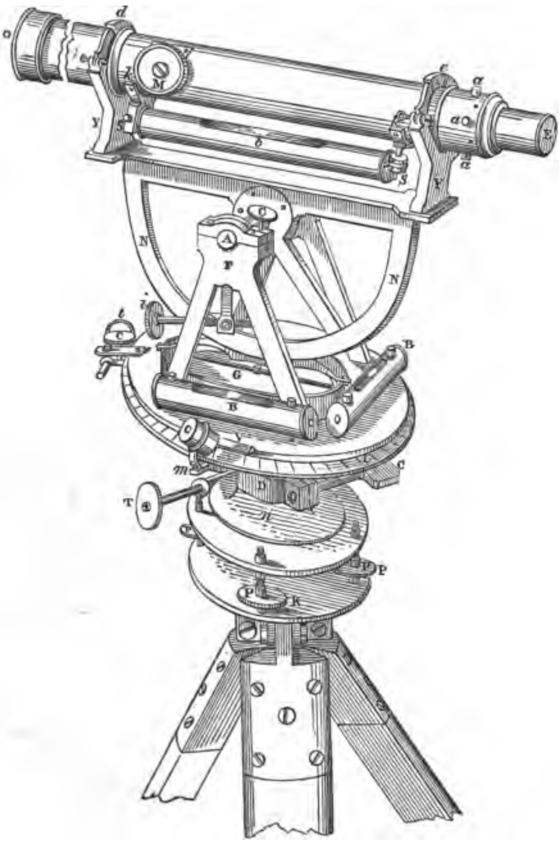
SIMMS

ON

DRAWING INSTRUMENTS.

AND

INSTRUCTIONS IN FIELD WORK



A FIVE-INCH THEODOLITE.

A TREATISE

ON THE

PRINCIPAL MATHEMATICAL

DRAWING INSTRUMENTS

EMPLOYED BY THE

ENGINEER, ARCHITECT, AND SURVEYOR.

BY F. W. SIMMS,

CIVIL ENGINEER AND SURVEYOR,

AUTHOR OF

"A TREATISE ON THE PRINCIPLES AND PRACTICE OF LEVELLING," AND OF A PAPER IN WEALE'S QUARTERLY PAPERS ON ENGINEERING, "ON SETTING OUT THE WIDTHS OF GROUND REQUIRED FOR THE WORKS OF A RAILWAY OR CANAL."

SECOND EDITION.

TOGETHER WITH A

DESCRIPTION OF THE THEODOLITE,

BY MR. HENRY JAMES CASTLE,

SURVEYOR AND CIVIL ENGINEER;

AND

INSTRUCTIONS IN FIELD WORK,

COMPILED FOR THE USE OF STUDENTS ON COMMENCING PRACTICE.

WITH NUMEROUS WOOD-CUTS.

JOHN WEALE,

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TO THE

SECOND EDITION.

THE publisher, in presenting a second edition of this little work, has extended its utility by the additional useful information, the more requisite at the present moment, of some Remarks written in the plainest language on the subject of Field Work, with which it is essential for the student to be familiar. Mr. Castle, also, has liberally contributed to the value of the Volume, by his description of the Theodolite, an engraving of which is added as a frontispiece.

JOHN WEALE.

February 10th, 1845.

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TO THE

FIRST EDITION.

THE following pages, which have been prepared during short intervals of an active professional employment, the writer hopes will give to the Student in Engineering, Architecture, and Surveying, all the information he may require respecting the construction and particular use of such Mathematical Drawing Instruments as are essential for him to possess in the practice of his profession. Usefulness, rather than making a large, and consequently expensive book, being the Author's object, he has inserted only an account of what may be termed the principal instruments now in use, and of the best construction, being convinced, that if these are well understood, there can arise no difficulty to the Student in the use of any other of the multifarious forms in which the same kind of instruments appear, as constructed

by different makers, chiefly to suit the whims of their customers.

The engravings have been made with particular care, from the instruments in the Author's possession and use, and in most cases are made to half the real size.

At the end of the book is inserted, as not unconnected with the subject, some practical hints in the management and use of drawing paper, and in drawing. Also two tables relative to Circles and Polygons, with some few rules for their application to practice; which, it is presumed, will be found useful, both in Geometrical Constructions, and also in Arithmetical Calculations.

F. W. S.

GREENWICH, July 14th, 1837.

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PRACTICAL HINTS, &c.

A TREATISE

ON

MATHEMATICAL

DRAWING INSTRUMENTS.

THE COMPASSES.

The compasses are an instrument so well known, that it would be superfluous to enter into a minute description of them, or of the various uses to which they may be applied. The best are constructed with joints of two different metals, as steel and brass, whereby the wear is more equal, and the motion of the legs uniform and steady, and not subject to sudden jerks in opening or shutting. This motion will occasionally require some adjustment to render it uniformly smooth, and to move stiffer or easier at pleasure, but so that they may keep steadily any position that may be given to them. This adjustment is performed by the application of a turnscrew

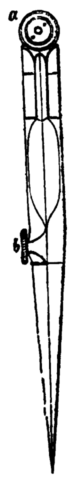
to the axis of the joint. In the common compasses a simple screw forms the axis upon which the legs move, and may be turned with a screwdriver of the ordinary construction, but in the best made instruments a steel pin passes through the joints, having at one end a head of brass riveted fast upon it, and on the other end a similar plate is screwed, which is therefore a nut, on a diameter of which is drilled two small holes for the application of a lever of a particular kind (described at page 27). This is shewn at *a* in the engraving on the adjoining page 3. The points of a well made instrument should be of steel so tempered, as neither to be easily bent or blunted; not too fine and tapering, and yet meeting closely when the compasses are shut.

As some of the numerous uses to which this instrument may be applied, the following may be mentioned. To take any extent, or length between the points of the compasses, and to set it off, or to apply it successively upon any line. To take any proposed line between the points, and by applying it to the proper scale, to find its length. To set off equal distances upon a given line. To describe circles, intersecting arcs, &c. To make an angle equal to any given angle. To lay off an angle of a given

quantity upon an arc of a circle from the line of chords, &c. To measure any arc or angle upon the line of chords, &c. To construct any proposed figure in plotting, or drawing plans, &c. &c.

THE HAIR COMPASSES.

This instrument is represented in the adjoining figure, and is constructed in the same manner as those above described. *a* represents the joint before mentioned. The only difference consists in a contrivance, *b*, whereby the lower, or point half of one shank, can be moved a very small quantity either towards or from the other point, which is useful when a distance is required to be taken with the utmost possible exactness. This contrivance consists of a fine spring and screw, by which, when the compasses are opened nearly to the required extent, by the help of the screw *b* the points may be set with great precision, which cannot be done so well by the motion of the joints alone.



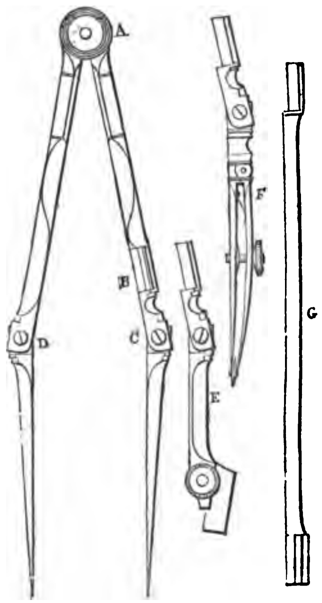
COMPASSES WITH MOVEABLE POINTS.

In the smaller and more portable cases of drawing instruments, it is customary to insert a larger sized

pair of compasses, of which the point half of one of the legs is transmoveable, to admit of adapting singly a pen, a pencil, or a dotting point. The pen point is used for drawing circles or arcs with ink, and is constructed like the drawing pen to be hereafter described. The pencil point is a tube adapted to hold a piece of black lead pencil or crayon for describing circles or arcs that are not to be permanent. And the dotting point consists of two blades, similar to those of the drawing pen, but rounded at the points, between which revolves a small wheel, with numerous points round its circumference, resembling the rowel of a spur. The space between the blades being supplied with Indian ink, and the wheels rolled upon the paper, as the compasses describe a circle, or arc, each point, as the wheel revolves, will pass through the ink, and transfer it to the paper beneath, making equidistant dots in the circle which the compasses describe.

The moveable points have a joint in them, just under that part which locks into the shank of the compasses, by which the part below the joint may be set perpendicular to the plane on which the lines are described, when the compasses are open.

An additional piece, called a lengthening bar, is frequently applied to these compasses, which, by lengthening the moveable leg, enables them to strike larger circles, or measure greater extents than they otherwise would perform. When this is applied, the moveable point has a joint similar to those on the pen and pencil points, and for a similar purpose. The annexed engraving represents this instrument and its appendages.



A, the compasses, with a moveable point at B.

C and D, the joints to set each point perpendicular to the paper.

E, the pencil point.

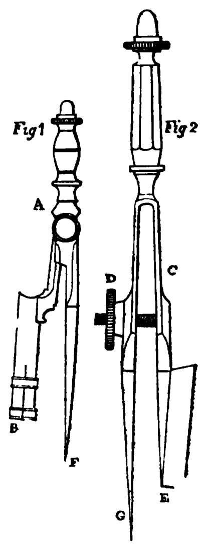
F, the pen point. (This is represented with a dotting wheel; the pen point and the dotting point are similar in shape to each other.)

G, the lengthening bar.

BOW COMPASSES.

These are a small pair, either having a point for ink or pencil. They are used to describe small arcs or circles, which they do more conveniently than large compasses, not only on account of the size, but also from the shape of their head, which rolls easily between the fingers, and can be turned round as delicately as they require to be moved, for drawing very minute circles.

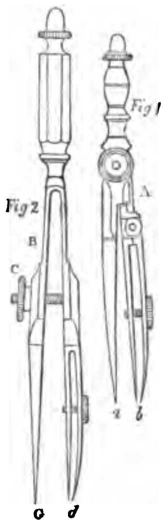
The adjoining figures represent the pencil bow as suited for describing arcs of different radii. Fig. 1 is a construction adapted for describing arcs of a radius intermediate between those described by the above named compasses, and those capable of being produced by the bows represented by Fig. 2. In Fig. 1, the pencil point B, and the centre point F, can be opened a considerable width by the joint A, whilst in



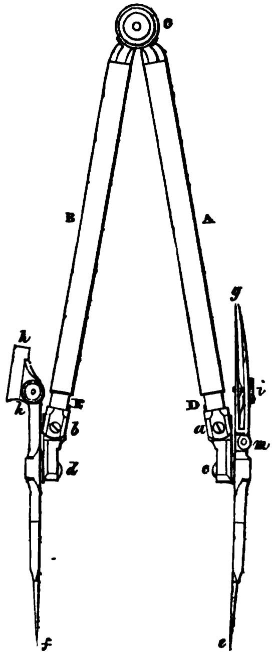
the other construction Fig. 2, the corresponding points E and G are limited in their opening, the two blades carrying the points being formed out of

one solid piece of steel, and tempered so as to form a spring at the upper part, corresponding with the joint A in Fig. 1; the spring of the two blades is then kept in obedience by an adjusting screw D, by which the two points may be set to any required degree of minuteness, and very small circles may be described with a precision that could not be expected, or scarcely attempted by the construction of Fig. 1.

The pen bows are represented in the annexed engraving. Their construction is similar to the pencil bows last described. In the pen point of Fig. 1, there is a second joint just below the letter A, by which, when the instrument is open for use, the pen may be set perpendicular, or nearly so, to the paper, which is essential in the use of the drawing pen. This is a corresponding contrivance with that described at page 4, as applicable to the compasses with moveable points. In Fig. 2, B shows the spring blades carrying the points G and *d*, and C the adjusting screw to set those points to the required radius.



TUBULAR COMPASSES.



The adjoining engraving represents this admirable instrument, the contrivance of Mr. Brunel. It may be used as an ordinary pair of compasses, either with two fine points, a pen point, or a pencil point, and is capable of describing circles to any extent of radius, from an eighth of an inch to fourteen inches and a half, and with the advantage of reversing points which may be changed from pen to pencil, &c. without deranging the setting of the instrument, when opened to any definite extent.

A and B are the two principal legs of the instrument, consisting of tubes moveable about, a very nicely constructed joint at C. Within these, are two sliding tubes, E and D, which draw out their whole length, and are accurately fitted to the principal tubes A and B, so that they may be drawn out to

their required extent with a smooth and steady motion, not subject to sudden stoppages, or to move with equally sudden jerks, a proof of bad workmanship, but uniformly, and not too easy. To assist in this, their inner extremities are made to act as springs within the tubes wherein they slide, thus increasing their friction.

The outward extremity of each of the sliding tubes, E and D, terminates in a square headed joint, *a* and *b*; upon these move the pieces, *c* and *d*, which carry the point limbs of the compasses. The joints *a* and *b*, in this instrument, correspond with the joints C and D of the compasses, with moveable points described at page 4, and are used for a similar purpose, namely, to set the point limbs perpendicular to the paper, and consequently parallel to each other, at whatever opening the legs of the compasses may be extended to. In our engraving, the two point limbs, *f h* and *e g*, are represented as set nearly perpendicular by this means.

The two pivots represented at *c* and *d*, connect the point limbs *f h* and *e g* to the two carrying pieces, which are jointed to the tubes at *a* and *b*; these pivots also give the means of inverting the position of the points, that is to say, the limbs can be turned

upon these pivots so as to make the points *e* and *g*, or *f* and *h*, change places. By this simple and ingenious contrivance, the draftsman, after having used the two fine points, *e* and *f*, for fixing with precision the opening of the compass to his required radius, may obtain a pencil point to describe a corresponding arc or circle, by simply turning the pencil limb, *h f*, round on its pivot *d*, which will cause the point of a pencil or crayon placed in the tube *h*, to change places with the fine point *f* of the compasses; and, as the pivot is (or ought to be) at right angles to a line connecting the points *f* and of the pencil at *h*, the latter will exactly take the place of the former at the same extent or opening *e f*. In like manner, by turning the pen limb, *e g*, round its pivot *c*, the pen point may be made to occupy the position of the fine point *e*, to draw a permanent circle of the radius *e f*, or whatever the compasses may have been set to in the first instance.

The milled headed screw, represented at *k*, is for the purpose of fixing a pencil firmly in its tube *h*; the screw *i* is for adjusting the blades of the pen point *g*, between which the ink is inserted, to any required degree of fineness, so as to produce a corresponding fine or coarse circular line. The joint

m, by removing altogether the screw *i*, gives the means of opening the blades for the better cleansing them after use, and is the same as applied to most drawing pens.

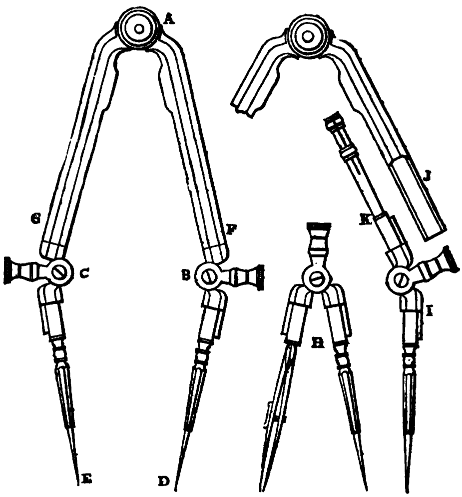
PORTABLE OR TURN-IN COMPASSES.

This forms in itself a complete portable case of drawing instruments, consisting of a large pair of compasses with moveable points, which are also so contrived, that one forms in itself a small pencil bow, the other a pen bow; and when the whole instrument is put together and folded up (or the points *turned in*, from whence is derived the name of *turn-in-compasses*), they occupy but a space three inches long, and may be carried in the pocket without being an incumbrance.

In the annexed engraving, the left hand figure represents the instrument, when all its parts are together. The principal legs of the instrument are F and G, moveable as usual by a joint at A. The lower joints, B and C, afford the means of setting the point limbs, D and E, perpendicular to the paper, as explained before when describing the last instrument.

Each of the point limbs may be removed from the legs F and G, and by means of their joints, B and

C, form perfect instruments, the one a pen bow represented at H, and the other a pencil bow, shown at I K; the point limbs of these lesser instruments are all adapted to slide into the principal legs, F and G, of the larger one, which are made hollow for their reception; a section of the limb F is shown at J, to convey to the reader a better idea of the arrangement.

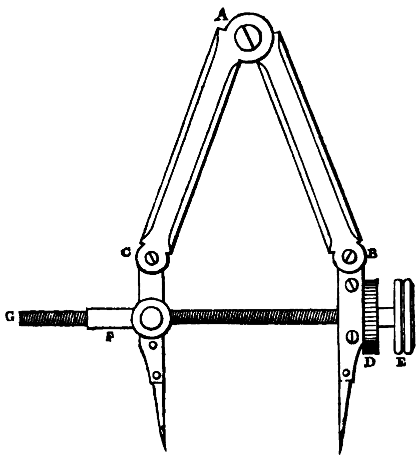


It may easily be seen from the engraving, that by reversing either of the points in the principal instrument, it may be supplied with a pen or pencil as may be required, leaving the other fine or plain point, E or D, to act as a centre.

A sheath or case is sometimes applied to insert the instrument for carriage. There are also various forms and arrangements of the parts, occasionally given to the instrument to suit the fancies of individuals, but the one we have described above will give the reader a correct notion of the general character of this class of instruments.

LARGE SCREW DIVIDERS.

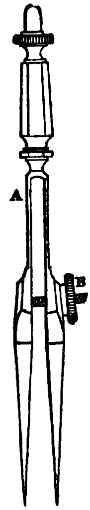
We have now to describe another class of compasses, such as are used for accurately dividing lines, &c. into a definite number of equal parts, or for setting off equal distances; the first of these is the large screw divider, represented in the adjoining figure.



A is the centre about which the legs A C, and A B, open or shut. B and C are joints, by which the point limbs may be set perpendicular as usual; the extent or opening between the points is regulated by a screw passing through a socket, F, and terminated at the other extremity by a milled head, E, by which the screw is turned round. Between this milled head and the nearest point limb, is fixed what is called a micrometer head, decimally divided round its outer or cylindrical edge. One turn of the screw carries the micrometer head completely round; therefore, when part of a turn only is given to the screw, the divisions on the head show what fraction of a turn has been given, and if it be known what number of turns or threads of the screw are equal to one inch, the points of these compasses may be thus set to any small definite measure of length with the utmost precision, the index or zero for reading the fraction of a turn of the screw, is marked on the point limb below B. Thus this instrument may be considered as a beam compass of small dimensions and minute accuracy.

SPRING DIVIDERS.

This instrument, represented in the annexed engraving, is particularly useful for repeating divisions

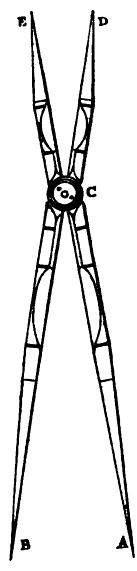


of a small but equal extent, a practice that has acquired the name of stepping, for which a small pair of hair compasses would also be found useful when the head is constructed as shown in the adjoining figure, or similar to that of the Bow Compasses, described at page 6, and for the reasons there stated. The upper part, forming the handle, is composed of brass or silver; whilst the lower part from A, towards the points, is made of one piece of steel of a spring temper, whereby the two points are always endeavouring to recede from each other, or open by their elasticity, which is counteracted by the adjusting screw B, by which it may be set to the required opening. This screw acts in the same manner as the micrometer screw, described as belonging to the last instrument, but with this difference, that it has not the means of pointing out the measure of the interval or extent between the fine points of the compasses, which measure must therefore be taken from a suitable scale.

WHOLES AND HALVES.

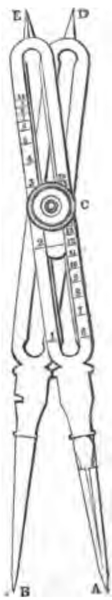
Having explained the general construction of the

most approved instruments of the smaller kind for describing circles and dividing lines, we come now to speak of those employed in copying and reducing drawings. And, first, of the instrument represented in the annexed engraving, which is the simplest form of proportional compasses, and capable of reducing or enlarging in one proportion only, namely, one-half, from whence its name of wholes and halves is derived. The points A and E are on one piece of metal, likewise the points B and D are at the extremities of another piece of metal, and straight lines connecting these points will pass through the centre C. The legs of the instrument are connected together by a joint of the usual form at C, placed one-third of the whole length from one extremity; consequently, whatever may be the extent of the opening of the points, A and B, it will always be double the extent of the opening of the other two points, D and E. Therefore, if the whole length of any line be taken between the opening of the two former points, the interval between the two latter points will be exactly one half the length of the same



line; consequently, this instrument affords the readiest means of dividing a line into two equal parts, or *vice versâ.* Its usefulness in dividing lines does not rest here, for if the original line has to be divided into any *even* number of parts, as, 2, 4, 6, 8, &c. &c., by constantly taking the half of the half, in the same manner as taking the half of the original line in the first instance, the requisite even number of subdivisions may be obtained.

PROPORTIONAL COMPASSES.



This instrument is a very useful and necessary appendage to a case of drawing instruments, and although rather expensive in its original cost, it very soon repays its owner in saving of both time and trouble.

The proportional compasses consists of two equal and similarly formed parts or limbs, A E, and B D (see the annexed engraving), which are represented as opening upon a centre C, and forming a double pair of compasses or points, A B, E D. When shut up, the two limbs appear as one, and a small stud fixed on one fits into a notch made in the other, and retains the

instrument exactly in its closed position; the two points also, at each extremity, then coincide and become as one point. When thus closed, the dovetailed slits shown in the engraving as made in each limb, both equal and similar, also coincide, and appear as one slit, and in this position only can the adjustment be made for any required proportion; that is to say, the instrument must always be closed, in order to slide and fix the centre C in its proper place, that the opening of the large points, A B, may be double, triple, quadruple, &c. as may be required of the opening of the small points, E D, at the other extremity.

The centre consists of a pivot, or steel pin, which passes through two dovetailed pieces of brass, nicely fitted to slide in the beforenamed slits, and also through a circular nut or collar on each face, which answers the double purpose of keeping the dovetailed pieces of brass in their slits, and also firmly clamping them together by means of the milled head C, when they are moved to the position required for the centre to occupy; on the dovetailed pieces, a line is drawn for the zero to set the centre by, which in our engraving is represented as coinciding with the division on the limb marked 2, and nearly with the one marked 12. On the face of each limb there

are two sets of divisions, one denominated "Lines," a second "Circles," a third "Plans," and the fourth "Solids."

When the zero of the centre on the dovetailed sliding piece is set to the division marked 1, on the line of lines, and clamped by turning the milled head C, any opening of the compasses will be *equal* at both extremities; when the zero is in like manner set to 2 on the line of lines, then the proportion between any opening of the large points A B, will be two to one, or twice as great as the opening of the smaller points D E; and, consequently, any extent taken between the large points may be accurately divided into two parts by the smaller ones. Also, when the zero is set to the division marked 3 on the same line, the proportion of any opening will be 3 to 1, or that of the smaller points will be one-third of the extent of the larger points; and the same of the remaining divisions on the line, which extend to ten.

Of the line marked "Circles," on the opposite edge of the same face of the instrument, the divisions are numbered from 6 to 20; and the index or zero being set to any number, the points will open in the proportion of the radius of a circle, to the side of an inscribed polygon of that number of sides. Thus, if

it be set to the division marked 8, and the points A B are opened to the radius of any circle, the opening of the smaller points D E will divide the circumference into eight equal parts.

The other lines of divisions, namely those marked "Plans" and "Solids," are on the other face of the instrument; these are, in fact, lines of square and cube roots. The line of Plans, or squares, shows the proportion between the areas of similar plane figures. Thus, set the zero to the division marked 3, and measure the side of a square in the large points A B, the opening of the short ones D E will then be equal to the side of a square, which will be one-third of the area of the other. The same of triangles, circles, or any other regular plane figures.

To find the square root of a given number. Shut the compasses, and set the zero to the number given upon the line of Plans; open the instrument, and from any scale of equal parts take the number between the larger points A B, then apply the smaller points D E to the same scale, and the distance between them will be equal to the square root of the distance between the points of the larger legs A B.

The mean proportional between two given numbers, is the square root of their product, and may be

found by the proportional compasses; thus, required the mean proportional between 2 and 4½. Open the compasses with the zero or index set against 9, the product of the two given numbers, till the distance between the larger points is equal to 9, taken from some scale of equal parts; then the distance between the smaller points will be equal to 3 of the same scale, and is the mean proportional between 2 and 4½, for as 2 : 3 :: 3 : 4½.

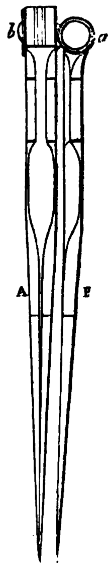
The line of "Solids" expresses the proportions between cubes or spheres. Thus, set the zero to the division marked 2 on the line of solids, then measure the diameter of any sphere, or the side of a cube with the larger points A B; the smaller points will then show the diameter of a sphere, or side of a cube which will have one half the solid content of the former. In like manner, by setting the zero to the divisions marked 3, 4, &c., the interval between the larger and smaller points of the instrument will show respectively the diameters, &c. of spheres, of which one shall have three or four times the solid contents of the other.

Also the cube root of any number may be found, by setting the zero upon the given number upon the line of solids, &c., as described for obtaining the square root by means of the line of Plans.

Proportional compasses of the best construction are sometimes made with a clamp and tangent screw, for setting the zero with the utmost precision; this, however, is seldom used; and the instrument, as we have described it above, is the kind in general requisition.

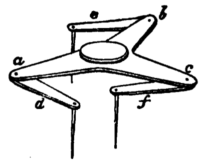
TRIANGULAR COMPASSES.

The adjoining figure represents this instrument as it appears when closed up for packing in its case. That which appears in the engraving as one limb A, consists of a pair of compasses precisely of the ordinary construction. The single point limb B has a compass joint at *a*, by which its point may be opened at right angles to the plane of the pair of compasses A, when the three points will form a triangle. The compass joint *a* is firmly attached to the centre of the compasses A, which, by means of a nut and screw *b*, may be turned round without moving the limbs, of which it is the centre. The double motion thus given to the point limb B (both at right angles to, and parallel to the plane of the compasses A), partakes of the nature of an universal joint, and



enables the three points of the instrument to be placed at the angular points of any shaped triangle whatever, be it ever so obtuse angled. Also, by the same means, the three points may be brought into one straight line. This instrument, it will be obvious from the description, is chiefly useful in transferring points from one paper to another, and is very useful in copying mechanical drawings. The two points of the compasses A being set upon such points of the drawing as are already copied, the third point B of the instrument may be moved by its universal joint *a*, *b*, to rest upon any other point, and then by similarly applying the points of A to the corresponding points on the copy, the new point of the original may be correctly transferred to it, by means of the limb of the instrument B.

Another form of triangular compasses is represented in the annexed engraving. *a*, *b*, *c* is a solid tripod, having at the extremity of each arm a limb, *c d* and *e*, moving freely upon

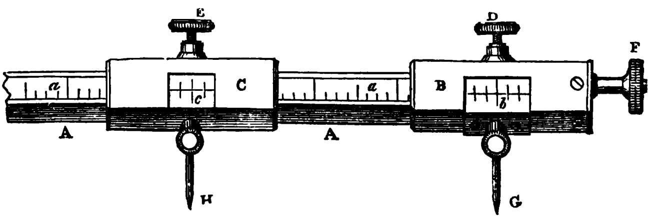


centres, by which they may be placed in any position with respect to the tripod and each other. These limbs carry points at right angles to the plane of the instrument, which may be brought to coincide

with any three given points on the original drawing, and then transferred to the copy as above described.

BEAM COMPASSES.

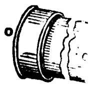
The compasses we have hitherto been describing are such as are applicable to general purposes, and will describe arcs or circles, from the most minute radius, to those of upwards of a foot, and also for setting off smaller measures of length; when, however, it is required to set off with accuracy distances of considerable extent, recourse must be had to the instrument we are now about to describe, and may be procured of any length to suit the wants of the purchasers.



The above engraving represents this instrument, which consists of a beam, A A, of any length required, generally made of well seasoned mahogany; upon its face is inlaid throughout its whole length a slip of holly or box wood, *a a*, upon which are engraved

the divisions or scale, either feet and decimals, or inches and decimals, or whatever particular scale may be required; those made for the use of the persons engaged on the ordnance survey of Ireland were divided to a scale of chains, 80 of which being equal to six inches; which, therefore, represented one mile, that being the scale to which that important survey is being plotted. Two brass boxes, B and C, are adapted to the beam; the latter may be moved, by sliding, to any part of its length, and fixed in position by tightening the clamp screw E. Connected with the brass boxes are the two points of the instrument G and H, which may have any extent of opening by sliding the box C along the beam, the other box, B, being firmly fixed at one extremity. The object to be attained, in the use of this instrument, is the nice adjustment of the points G H to any definite distance apart; this is accomplished by two vernier or reading plates *b c*, each fixed at the side of an opening in the brass boxes to which they are attached, and afford the means of minutely subdividing the principal divisions *a a*, on the beam*, which appear

* For a description of the Vernier, see pages 5, 6, &c. of a "Treatise on Mathematical Instruments employed in Surveying, Levelling, and Astronomy," by the Author of this book.



superior kind of beam compasses, the box furnished with a tangent or slow motion which the setting of the points or the divisio done with the utmost precision in the sam as the vernier b by means of the screw apply the points to a similar detached sc the adjustment is perfect, the interval of t G H, will measure on it the distance to w were set on the beam. If they do not, b small a quantity, it should be corrected, b the screw F till the points exactly measure t tity on the detached scale; then, by loosenin screws which hold the vernier b in its place, t of the vernier may be gradually changed, t coincides with the zero on the beam, and the ing the screws again, the adjustment will be

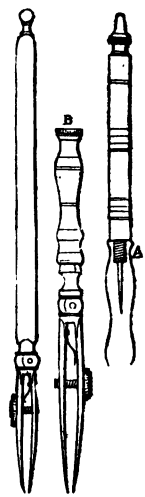
KNIFE, FILE, KEY, AND SCREW DR

The annexed engraving represents a v appendage to a case of drawing instrumen will be too apparent to need much descrip

A is the knife blade, B, the file, C, the sc and D, the key, which is adapted to fit the

compasses for tightening or loosening them as may be required. This is the instrument alluded to at page 2.

DRAWING PENS.



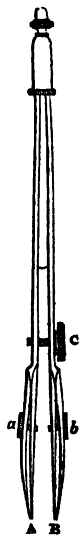
These are made as represented in the annexed engraving. The left hand figure shows the form of the best kind; the handle is of ivory, and the blades have a joint whereby they may be opened for the purpose of more effectually cleaning them after use. The right hand figure, which is in two parts, shows an older form of construction, the part A, to which is attached a pricker, or protracting pin, screws into the part marked B, making the handle of sufficient length to use conveniently as a drawing pen, thus combining two instruments in one.

The milled headed screw which is represented as connecting the blades together, is for the purpose of setting their points at any opening to draw a line of an assigned thickness. In using the pen, it should be slightly inclined in the direction of the line to be drawn, taking care, however, that the edges of both the blades touch the paper; these observations are equally applicable to the pen point of any of the compasses

before described, observing, as before noted, that whenever a circle or an arc of more than about an inch radius is to be described, the point should be so bent that the blades of the pen be nearly perpendicular to the paper, and both of them touch it at the same time.

THE ROAD PEN.

This instrument consists of two pens, A and B, so arranged with a spring which gives them a tendency to separate from each other to the extent of about half an inch, which tendency is counteracted by a screw C, whereby the pen points may be set to any required interval within the above limit. The screws *a* and *b* are for the purpose of setting the points of the blades to draw lines of any assigned degree of fineness, as explained above, for the ordinary drawing pen. The use of this instrument, is to draw two lines parallel and close to each other at the same time, whereby perfect parallelism may be secured; it is usually known by the name of the "Road Pen," having originally been designed to draw lines of road upon maps, both sides being drawn at the same time. For such a purpose it is very con-



venient, as one side, or fence, may be drawn with a stronger line than the other, which is frequently done on general maps as a distinguishing mark for principal or turnpike roads. In like manner, it is useful in drawing lines of canal, where the bounding lines are generally more nearly parallel than on public roads; besides which, it may be successively used in mechanical and architectural drawings, where extremely close parallel lines are very frequently required.

THE DOTTING POINT.

The great expense of time in dotting by hand such lines upon a drawing as may be essential to be shown, and yet not drawn in full, may be obviated by the use of this instrument. It in all respects resembles a drawing pen, except that the points are not so sharp. On the back blade, as seen in the engraving, is a pivot, on which may be placed a dotting wheel, *a*, resembling the rowel of a spur; the screw *b* is for opening the blades to remove the wheel for cleaning after use, or replacing it with one of another character of dot. The cap *c*, at the upper end of the instrument, is a box containing a variety of

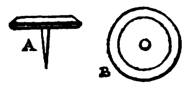
dotting wheels, each producing a different shaped dot. These are used as distinguishing marks for different classes of boundaries on maps; for instance, one kind of dot distinguishes *county* boundaries, another kind, *parish* boundaries, a third kind, distinguishes that which is both a county and a parish boundary, &c. &c. In using this instrument, the ink must be inserted between the blades above the dotting wheel, so that, as the wheel revolves, the points shall pass through the ink, each carrying with it a drop, and marking the paper as it passes. It is sometimes stated as an objection, that the wheel will often revolve many times before it begins to deposit its ink on the drawing, thereby leaving the first part of the line altogether blank, and in attempting to go over it again, the first made dots are liable to get blotted; at all events, the line is likely to consist of dots of different sizes, which is at least unsightly. This evil may be mostly remedied by placing a piece of blank paper over the drawing to the very point the dotted line is to commence at, then begin with drawing the wheel over the blank paper first, so that by the time it will have arrived at the proper point of commencement, the ink may be expected to flow over the points of the wheel and make the dotted line perfect as required.

THE PRICKING OR TRACING POINT.

This instrument consists of a pair of forceps, which firmly hold a needle point, or blunt point *a*, by means of a sliding ring *b*. Its use, which scarcely needs pointing out, is chiefly in copying drawings, the original being laid upon the paper intended to receive the copy, and held down by weights to prevent its shifting in position. The principal points are transferred to the copy, by pricking through the original with a very fine needle. This method of copying cannot be resorted to when the original is of considerable value. When such is the case, a common method of copying is by placing between the drawing and the intended copy a sheet of thin paper (such, for instance, as bank post paper), one face of which has been sprinkled with black lead, and rubbed till it be uniformly covered, and then as much wiped off as would come away with gentle rubbing. This being placed with the blacked part towards the intended copy, a blunt point, substituted for the needle point in the instrument, may be drawn with gentle pressure over the lines of the original without damaging it, and the

blacked paper will leave corresponding lines on the fair sheet beneath it. By reversing the needle in the instrument, leaving the eye end instead of the point exposed, and using it edgeways, it will be found to be a fine and smooth tracer.

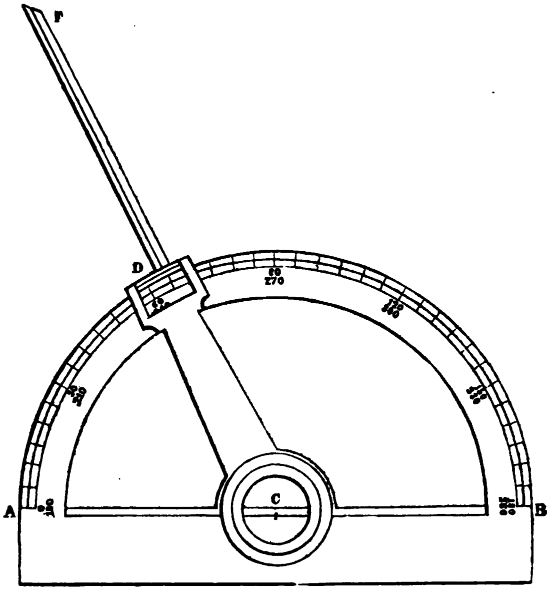
DRAWING PINS.



These require but little explanation. They are used to hold paper down upon a drawing or other board in any required position, and in most cases answer better than heavy weights, which are frequently used for that purpose, as the board may be shifted from place to place without moving the paper. They consist of a brass head, with a steel point at right angles to its plane. A represents it as seen edgewise, and B as seen from above.

PROTRACTORS.

We have now explained the construction of such instruments as are used for the purpose of drawing lines, whether straight or curved, and hence producing geometrical figures; we shall now exhibit the best form of protractors which are essential in laying down angles.



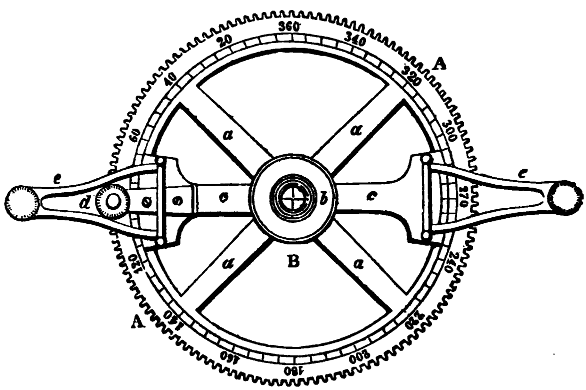
The above figure represents a semicircular protractor. The edge is divided into 180 degrees, and subdivided to half degrees or thirty minutes, and numbered both from A and B for convenience of plotting. Round the edge is carried a vernier D, which subdivides the principal divisions into single minutes. The vernier is attached to an arm forming a radius to the semicircle, which is extended beyond the circumference as far as F, and has on the extended part a fiducial edge, on which the angular line is to be drawn. The centre of the instrument

is at C, which is visible from above, by the centre upon which the vernier radius moves, being a ring placed concentric with the centre C. To use this instrument, it is only necessary to set the vernier to the given angle; then place the protractor, so that the fiducial edge A B may in every part exactly coincide with the line already given, and the centre C, with the given angular point. A line then being drawn along the fiducial edge from D towards F, will be the direction of the line forming the angle required; and upon moving the protractor, such line may be produced and connected with the angular point C. In adjusting the fiducial edge A B upon the given line, so that the centre C may *exactly* coincide with the given angular point, there is a certain degree of practical difficulty (we are now speaking of where great accuracy is aimed at). It is not therefore essential, in setting the instrument, to have any regard to the given angular point, but only to set the edge A B nicely upon the given line. Then with a needle point make three punctures in the paper; one near the extreme point F, a second at the circumference of the arc at D, and the third as nearly as possible at the centre C. The protractor may then be removed, and if all has been accurately performed,

these three points will be in one straight line, which may be transferred to pass through the given angular point by a parallel ruler.

THE CIRCULAR PROTRACTOR.

Our engraving represents one of the best kind of



protractors. It is a complete circle, A A, connected with its centre by four radii, *a a a a*. Like the instrument last described, the centre is left open, and surrounded by a concentric ring or collar, *b*, which carries two radial bars, *c c*. To the extremity of one bar is a pinion, *d*, working in a toothed rack quite round the outer circumference of the protractor. To the opposite extremity of the other bar, *c*, is fixed a vernier, which subdivides the primary divisions on the protractor to single minutes, and by estimation

to 30 seconds. This vernier, as may readily be understood from the engraving, is carried round the protractor by turning the pinion *d*. Upon each radial bar, *c c*, is placed a branch *e e*, carrying at their extremities a fine steel pricker, whose points are kept above the surface of the paper by springs placed under their supports, which give way when the branches are pressed downwards, and allow the points to make the necessary punctures in the paper. The branches *e e* are attached to the bars *c c*, with a joint which admits of their being folded backwards over the instrument when not in use, and for packing in its case. The centre of the instrument is represented by the intersection of two lines drawn at right angles to each other on a piece of plate glass, which enables the person using it to place it, so that the centre, or intersection of the cross lines, may coincide with any given point on the plan. If the instrument is in correct order, a line connecting the fine pricking points with each other would pass through the centre of the instrument, as denoted by the before-mentioned intersection of the cross lines upon the glass, which, it may be observed, are drawn so nearly level with the under surface of the instrument, as to do away with any serious amount of

parallax, when setting the instrument over a point from which any angular lines are intended to be drawn. In using this instrument, the vernier should first be set to zero (or the division marked 360) on the divided limb, and then placed on the paper, so that the two fine steel points may be on the given line (from whence other and angular lines are to be drawn), and the centre of the instrument coincides with the given angular point on such line. This done, press the protractor gently down, which will fix it in position by means of very fine points on the under side. It is now ready to lay off the given angle, or any number of angles that may be required, which is done by turning the pinion *d* till the opposite vernier reads the required angle. Then press downwards the branches *e e*, which will cause the points to make punctures in the paper at opposite sides of the circle; which being afterwards connected, the line will pass through the given angular point, if the instrument was first correctly set. In this manner, at one setting of the instrument, a great number of angles may be laid off from the same point.

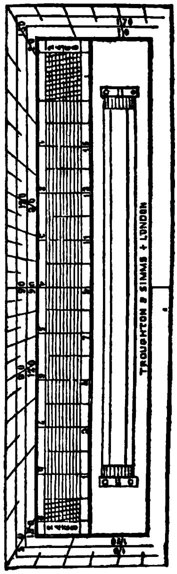
As described for the last instrument, it is not essential that the centre be over the given point, when applied to the given line, provided the pricking

points exactly fall upon the line, for an imaginary line connecting the pricking points in this instrument, correspond with the line A B, the diameter of the protractor last described. Sometimes, instead of a rack and pinion motion, a third radial arm is attached to the centre at right angles to the other two, upon which is fixed a clamp and tangent screw, by which the vernier is not only fixed in position upon the circular limb of the instrument, but by the tangent, or slow motion screw, it may be set to the required angle with the utmost precision.

PLAIN CIRCULAR AND SEMICIRCULAR PROTRACTORS.

Other and very useful protractors are made, consisting of a circle or semicircle, without verniers, slow motion screws, or any other appendages, having simply a fiducial circular edge nicely divided to degrees and half degrees, or more minute subdivisions, if the instrument is sufficiently large to admit of them. A very useful instrument of this kind has a diameter of six inches, and will be found sufficiently accurate for most ordinary purposes, and not above one third of the cost of the above named instrument, which, however, must be resorted to, when the utmost attainable accuracy is required.

THE PLAIN SCALE.



This instrument is represented in the annexed figure. It is usually made of ivory, 6 inches long, and $1\frac{3}{4}$ broad; it has on it two diagonal scales, one half the size of the other, on the same plane or face of the instrument, which, for distinction sake, we will call the upper side, and which is represented in our engraving. These diagonal scales consist of eleven parallel lines drawn equidistant from each other, and divided by vertical lines into equal parts of half an inch long, and numbered from right to left, 1, 2, 3, &c. The top and bottom lines of the extreme half inch space to the right is subdivided into ten equal parts, and each of these again subdivided into ten equal parts, by diagonal lines drawn from the tenth below to the ninth above, from the ninth below to the eighth above, from the eighth below to the seventh above, &c., till from the first below to the nothing above, so that by these means the half inch space is sub-

divided into 100 equal parts. Thus, if each of the half inch spaces be considered to represent unity, each of the first subdivisions will express $\frac{1}{10}$ of 1, and each of the second subdivisions, taken on the diagonal lines counting from the top downwards, will express $\frac{1}{10}$ of the last subdivisions, or $\frac{1}{100}$ of the half inch spaces (or primary divisions).

If each of the half inch spaces (or primary divisions) be considered as representing 10, then each of the first subdivisions will express 1 (or unity), and each of the second $\frac{1}{10}$ of unity.

Again, if each of the primary divisions (or half inch spaces) be considered to represent 100, then each of the first subdivisions will express 10, and each of the second subdivisions 1 or unity, &c. &c.

The method of taking distances from the scale may be thus shown. Suppose the distance to be 347 on the diagonal line joined to the 4th subdivision on the top line. Count 7 downwards, reckoning the distance of each parallel as 1; there set one point of the compasses, and extend the other till it falls on the intersection of the third primary division with the same parallel in which the other point of the compasses rests, and their opening will then express a line of 347, 34.7 or 3.47 according as we may have con-

sidered the primary divisions to represent one hundred, ten, or unity.

The smaller diagonal scale is formed by dividing the half inch spaces into two, and the further or left hand quarter of an inch space is then diagonally divided as above described.

On the same, or upper face of the instrument, a protractor is formed round its edges, and after what has been said upon that instrument, nothing more than the mention of it is requisite in this place.

On the under surface of the instrument, a variety of scales are engraved, among which are the following:—

Line of	Chords,	marked	C or C H.
„	Rhumbs,	„	R H.
„	Tangents,	„	T A.
„	Sines,	„	S I.
„	Secants,	„	S E C.
„	Longitudes,	„	L O N.
„	Latitudes,	„	L A.
„	Inclination of Meridians,	„	I M.
„	Hours,	„	H O.

Besides scales having the following number of equal divisions to the inch:—30, 35, 40, 45, 50, and 60.

The line of chords serves either to set off an angle

from a given point in any line, or to measure the quantity of an angle already laid down. The first is done by opening the compasses to the extent of 60 degrees upon the line of chords (which is always equal to the radius of the circle of projection), and setting one foot upon the angular point, with that extent describe an arc; then, taking the angular quantity from the same chord line, set it off from the given line upon the arch described, a right line connecting the given point with that upon the arc will form the angle required. To measure an angle already laid down, describe as before an arc of 60 degrees; and then, taking the extent with a pair of compasses between the lines which form the angle upon the said arc, the opening measured upon the same line of chords will denote the dimensions of the angle.

The line of rhumbs serves to lay down or measure, on a chart, the angle of a ship's course in navigation.

The lines of tangents, sines, and secants are used in the stereographical and orthographical projection of the sphere.

The line of longitudes, with the help of the line of chords, will show how many miles are contained in a degree of longitude at any latitude; thus, with a pair

of compasses, take from the line of chords the number of degrees of the given latitude, and apply the opening of the compasses to the line of longitude, placing one point of the compasses on the last division marked 60 on the longitudes, the other point will note upon the same line the number of miles in one degree of longitude at the given latitude. For example, if the given latitude be 60 degrees, take 60 from the line of chords, and applying one point of the compasses on the last division of the line of longitudes (marked 60), the other point will fall upon the division marked 30 on the same line, showing that 30 miles is contained in one degree of longitude at the latitude of 60 degrees.

The lines of latitudes, inclination of meridians, and of hours, are applicable to the practice of dialling, which does not fall within our present purpose.

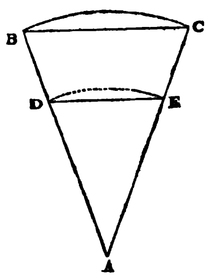
PLOTTING SCALES AND RULERS.

These need but few observations, as they are nothing more than scales of equal parts, the divisions being placed on a fiducial edge, by which any length may be pricked off on to the paper without using the compasses, whose points, by frequent use, destroy the fineness of the graduation. Plotting scales are made of various dimensions and of all varieties of gradua-

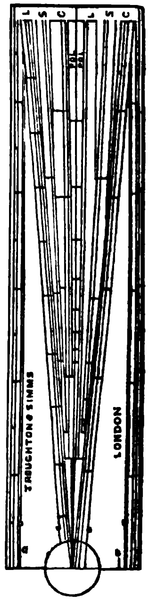
tion, to suit the purposes of the draftsman. Parallel rulers are also made of various constructions, some of them sliding and others with rollers, each having its own advantages. The plain scale above described is frequently fitted with rollers, making it at the same time a convenient small parallel rule; our own instrument, from whence the engraving was taken, is so constructed and shown in the cut.

THE SECTOR.

The sector derives its name from the fourth proposition of the sixth book of Euclid; where it is demonstrated, that similar triangles have their like sides proportional. The theory of its construction may be thus shown. Let the lines A B, A C, represent the legs of the sector, and A D, A E, two equal sections from the centre; then, if the points B C and D E be connected, the lines B C and D E will be parallel; therefore, the triangles A B C, A D E, will be similar, and consequently the sides A B, B C, A D, D E, proportional, that is as A B : B C :: A D : D E; so that if A D be the half, third or fourth part of



A B, then D E will be a half, third or fourth part of B C; and the same holds of all the rest. Hence, if D E be the chord, sine or tangent of any arc, or of any number of degrees to the radius A D, then B C will be the same to the radius A B.



This instrument is represented in the adjoining figure. It consists of two rulers, moveable round an axis or joint, from whence several scales are drawn on the faces of the rulers.

The two rulers are called legs, and represent the radii, and the middle of the joint expresses the centre of a circle.

The scales generally put upon sectors may be distinguished into single and double.

The single scales are such as are commonly put on plain scales, and may be applied in the same manner.

The double scales are those which proceed from the centre; each scale is laid twice on the same face of the instrument, viz. once on each leg. From these scales, dimensions or distances are to be taken, when the legs of the instrument are in an angular position.

THE DECIMAL SCALE.

This scale lies on the edge of the instrument, and is of the same length as the sector when opened (one foot is the usual length for sectors placed in cases of instruments), and is divided into 10 equal parts or primary divisions, and each of these into 10 other equal parts, so that the whole (foot) is divided into 100 equal parts.

SCALE OF INCHES.

This scale is laid close to the edge of the sector, and contains as many inches as the instrument will receive when opened. Each inch is divided into 10 equal parts.

THE LINE OF ARTIFICIAL NUMBERS.

The line of numbers (marked N), or Gunter's Line, as it is commonly called, is a line of geometrical proportion divided into nine unequal parts, beginning at 1 towards the left hand, and numbered on with 2, 3, 4, 5, &c. to 10, about the middle of the line, where another radius begins, and the same divisions are repeated, numbered as before to 10, at the end of the line on the right hand. Each of these primes,

or first grand divisions, are subdivided, according to the same ratio, into ten other parts, and each of these subdivisions (if the line be of sufficient length) should again be subdivided into ten other lesser parts. But upon pocket sectors, which, when opened, are twelve inches in length, only the part from 1 in the middle to 2 towards the right hand is a second time divided, and that but into five parts instead of ten, every one of which must be accounted as two centesms. In numbering, therefore, upon the line the figures 1, 2, 3, &c., which denote the primes, may be taken arbitrarily, either as units, tens, hundreds, or thousands; or they may represent the tenth, hundredth, or thousandth parts of an unit.

If 1, at the beginning of the line, be taken for unity, then 1 in the middle will be 10, and 10 at the end 100; but if the first 1 be accounted 10, then 1 in the middle will stand for 100, and 10 at the end for 1000. Again, if the first 1 be reckoned 100, then 1 in the middle will be 1000, and 10 at the end 10,000.

When, therefore, the first 1, or prime, represents 10 units, the figures 2, 3, 4, &c. to 1 in the middle, will stand for 20, 30, 40, &c.; and each tenth, or subdivision in the first radius of the line, will signify

1 unit; and each centesm in those tenths (if there be any) will be $\frac{1}{10}$ part of an unit; 1 in the middle will be (as before observed) 100; and the figures 2, 3, 4, &c. following, 200, 300, 400, &c.; each tenth, or subdivision in the second radius, will denote 10 units; and each centesm 1 unit. Again, let the first 1 represent 100, then the figures 2, 3, 4, &c. will signify 200, 300, 400, &c.; 1 in the middle 1000; and 10 at the end 10,000. According to this supposition, in the first radius, each tenth of a prime will be 10 units, and each centesm 1 unit; and in the second radius, each tenth of a prime 100, and each centesm 10.

In estimating decimal fractions upon the line, if 1 in the middle be accounted as unity, then will each prime in the first radius denote .1, each tenth of a prime ,01, and each centesm ,001. If 10 at the end of the line to the right hand be accounted as unity, the whole first radius will represent 1, and the numbers 2, 3, 4, &c. in the second radius will represent 2, 3, 4, &c.; every prime in the first radius, and every tenth of a prime in the second radius, will signify ,01, or one hundredth part of unity; and every tenth of a prime in the first radius, or centesm in the

second, will denote ,001, or one thousandth part of unity.

The numeration of the line thus explained, let it now be proposed to find the point thereon, answering to the number 436. For the four hundred, take the four first primes next the left hand; for the second figure ,3, take three tenths of the grand division between 4 and 5; and for the six units, reckon six centesms, or six parts of the next tenth, so that the extent from 1 at the beginning of the line to that point, will express the number 436. The same point will likewise represent the numbers 43,6. 4,36. or ,436; if the first 1 be accordingly accounted 10,1, or $\frac{1}{10}$ of unity.

To multiply upon the line, extend your compasses from 1 at the beginning, to the point representing the number of your multiplier. The same extent will reach from the number of your multiplicand to the product. Thus, if 125 were given to be multiplied by 42, extend the compasses from 1 to 42, and the same extent will reach from 125 to 5250.

To divide upon the line, extend the compasses backwards from the number of the division to unity. The same extent, laid the same way, will reach from the number of the dividend to the quotient. Thus,

if 5250 were to be divided by 125, extend the compasses backwards from 125 to unity, the same extent will reach the same way, from 5250 to 42.

THE LINES OF ARTIFICIAL SINES AND TANGENTS.

The line of artificial sines (marked S) consists only of the logarithms of the natural sines, transferred from a table of logarithms to the scale. They are numbered from the left to the right, with the figures 1, 2, 3, &c. to 10, which stands about the middle of the line; and so forward with 20, 30, 40, &c. to 90, at the end on the right. In the first part of the line, the grand divisions each represent one degree; so that if each prime be subdivided into twelve parts (as they commonly are upon sectors), each subdivision will signify five minutes. In the latter part of the line, the grand divisions, which are each ten degrees, being subdivided into ten parts, each subdivision will represent one degree; and according as they are again subdivided into four, three, or two parts, such second subdivisions contain fifteen, twenty, or thirty minutes each.

What has been said of the line of sines, is likewise to be understood of the line of artificial tangents (marked T), whose divisions begin also at 1, and run

on to 10 in the middle of the line, signifying single degrees. In the second part it runs on with 20, 30, &c. to 45, which stands at the end of the line; then returns back again to 90, where it began.

The use of these lines is in working proportions, whether arithmetical or geometrical; and also in trigonometrical solutions. Thus, in all proportions, three terms are given to find a fourth. Seek out, therefore, the first term, whether number, sine, or tangent, on its proper line; and in that point set one foot of the compasses, and extend the other to the second or third term, whichever of them is of the same name as the first: the same extent laid from the other term the same way, will reach to the fourth term required.

Example.—As the sine of 52°. 30′ : 85 :: radius, or the sine of 90° to the fourth number required.

Set one foot of the compasses in the line of artificial sines on 52°.30′, and extend the other foot to 90° on that line, the same extent will reach from 85 on the line of numbers to 107, the fourth term required.

THE DOUBLE SCALES.

These consist of the line of lines, or of equal parts marked L; the line of chords marked C; the

line of sines marked S; the line of secants also marked S, but placed on the reverse side of the sector; the line of polygons marked Pol; a line of tangents to 45° marked T; and also a second line of tangents from 45° to 75°. Each of these scales begin at the centre of the instrument, and are terminated near the other extremity of each leg; viz. the lines at 10, the chords at 60, the sines at 90°, and the tangents at 45°; the remainder of the tangents, or those above 45°, are on other scales beginning at $\frac{1}{4}$ of the length of the former, counted from the centre, and marked with 45, and run to about 76 degrees.

The secants also begin at the same distance from the centre, where they are marked with 10, and are continued to as many degrees as the length of the sector will allow, which is about 75°.

The angles made by the double scales of lines, of chords, of sines, and of tangents to 45 degrees, are always equal.

And the angles made by the scales of upper tangents, and of secants, are also equal; and sometimes these angles are made equal to those made by the other double scales.

The scale of polygons is put near the inner edge of the legs; their beginning is not so far removed from

the centre, as the 60 on the chords is. The beginning of this scale is marked 4, and from thence is figured towards the centre of the instrument to 12.

From this disposition of the double scales, it is plain, that those angles which are equal to each other when the legs of the sector are close, will continue equal to each other at every opening of the instrument.

METHOD OF USING THE DOUBLE LINES ON THE SECTOR.

When a measure is taken on any of the sectoral lines beginning at the centre, it is called a lateral distance; but when a measure is taken from any point on one line, to its corresponding point on the line of the same denomination, on the other leg, it is called a transverse distance.

The divisions of each sectoral line are contained within three parallel lines; the innermost being the line on which the points of the compasses are to be placed, because this is the only line of the three which goes to the centre, and is therefore the sectoral line.

LINE OF LINES.

Multiplication.—With the compasses, take from any convenient scale of equal parts the length of one

of the factors, and open the sector until the transverse distance between 10 and 10 is equal to it; then the transverse distance of the other factor (measured upon the same scale of equal parts) will represent the product.

Example.—Multiply 4 by 5, extend the compasses from the centre of the sector to 4 on the primary divisions (or take it from any other scale of equal parts), and open the sector till this distance becomes the transverse distance from 10 to 10 on the same divisions; then the transverse distance from 5 to 5, measured upon the same scale as the former, will equal 2 or 20. The answer:—

Division.— Make the lateral distance of the dividend the transverse distance of the divisor; the transverse distance of 10 will be the quotient.

Example.—Divide 20 by 4. Make 20, taken from any convenient scale of equal parts, the transverse distance of 4, then the transverse distance of 10 (measured upon the same scale) will be 5. The answer:—

It will readily be perceived that for the multiplication or division of high numbers, aliquot parts of both factors must be taken, and the result multiplied by the same. The application of the sector to such

common arithmetical operations is therefore of very limited (and doubtful) utility.

Proportion.—Two lines being given to find a third proportional.

Example.—The given lines = 2 and 6, a third proportional required. Take between the compasses the lateral distance of the second term 6 (either from the line of lines on the sector, or any convenient scale), and open the sector until this distance becomes the transverse distance to the first term 2; then the transverse distance of the second term 6, measured upon the same scale as the former, will equal 18, the third proportional required.

If the legs of the sector will not open so far as to let the lateral distance of the second term fall between the divisions expressing the first term, then take $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, or any aliquot part of the second term (such as will conveniently fall within the opening of the sector), and make such part the transverse distance of the first term; then, if the transverse distance of the second term be multiplied by the denominator of the part taken of the second term, the product will give the third proportional required. Thus, in the above example, take $\frac{1}{3}$ of 6 = 2, which make the transverse distance of 2 the first term; then the transverse dis-

tance of 6 the second term will be = 6, which, multiplied by 3, will give 18. The answer: —

Three lines being given to find a fourth proportional, open the sector until the lateral distance of the second term, or some aliquot part thereof, becomes the transverse distance of the first term; then the transverse distance of the third term will be the fourth proportional required, or such a submultiple thereof as was taken of the second term.

Example.—To find a fourth proportional to the numbers 2, 6, and 10.

Take the lateral distance of the second term 6, from any convenient scale of equal parts, and open the sector until that quantity, or any aliquot part thereof, becomes the transverse distance of the first term 2, then the transverse distance of the third term 10, taken from the same scale of equal parts, will give 30, the fourth proportional required.

TO DIMINISH A LINE IN ANY ASSIGNED PROPORTION.

Example.—Let it be required to diminish a line of 4 inches in the proportion of 8 to 7. Open the sector until the transverse distance of 8 is equal to the lateral distance of 7.

Mark the point where 4 inches will reach as a lateral distance taken from the centre, which will be in this case 6.86, and the transverse distance taken at that point will be 3 inches and a-half, the proportion required, that is, 8 : 7 :: 4 : 3½.

We may remark, once for all, that in all problems with the sector, if any given line is too long for the legs of the instrument, take ½, ⅓, or ¼, &c. of it, and the result multiplied by 2, 3, or 4 will give the quantity required.

The use of the sector in reducing drawings may be thus shewn:—Suppose a triangle was to be reduced to the proportion of 4 to 7.

Take the length of one side of the triangle in the compasses, and make it the transverse distance of 7 and 7; then take the transverse distance of 4 and 4, which will be the length of the corresponding side of the reduced triangle. Next take the length of another side of the given triangle, and make it the transverse distance of 7 and 7 as before. Then the transverse distance of 4 and 4 will be the length of the corresponding side of the reduced triangle, one point of the compasses being placed at the proper extremity of the first reduced line, describes an arc, with the length of the second line as radius. Lastly, the third side of the given triangle being made the transverse distance

of 7 and 7, and that of 4 and 4 being taken, another arc intersecting the former one, described from the opposite end of the first reduced line, will give the point to be connected with each end of the first reduced line, and the triangle will be completed.

In the same manner, any right-lined figure, of how many sides soever, may be reduced in any given proportion or augmented by the same rule.

To divide a given line into any proposed number of equal parts.

Make the length of the given line the transverse distance to the figures representing the number of parts required; then the transverse distance of 1 and 1 will divide the given line as required.

Example.—Suppose a line to be divided into 9 equal parts, take the length of the given line in the compasses, and open the sector until it becomes the transverse distance between 9 and 9; then the transverse distance of 1 and 1 will be the $\frac{1}{9}$ part of the given line, or such a submultiple of the $\frac{1}{9}$ part as was taken of the given line.

Or the $\frac{1}{9}$ part will be the difference between the given line, and the transverse distance of 8 and 8.

The latter of these methods is to be preferred when the part required falls near the centre of the instrument.

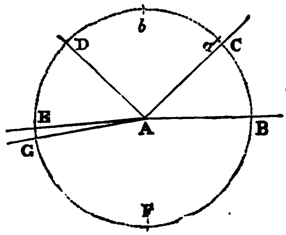
To make the line of lines represent any scale of equal parts, for drawing plans, elevations, &c. Thus, suppose a scale of one inch to five chains, or one inch to five feet were required. Take one inch in the compasses, and by opening the sector make it the transverse distance of 5 and 5; then the transverse distance of any other corresponding points, as 6 and 6, 7½ and 7½, will be that number of chains and links, or feet, &c., to the required scale.

LINE OF CHORDS.

The double scales of chords upon the sector are more generally useful than the single line of chords described on the plain scale; for, on the sector, the radius with which the arc is to be described may be of any length between the transverse distance of 60 and 60 when the legs are close, and that of the transverse of 60 and 60 when the legs are opened as far as the instrument will admit of. But with the chords on the plain scale, the arc described must be always of the same radius.

To protract or lay down a right-lined angle B A C, which shall contain a given number of degrees, suppose 46°.

Case 1. When the angle contains less than 60 de-



grees, make the transverse distance of 60 and 60 equal to the length of the radius of the circle, and with that opening describe the arc B C.

Take the transverse distance of the given degrees 46, and lay this distance on the arc from the point B to C.

From the centre A of the arc, draw two lines A C, A B, each passing through one extremity of the distance B C laid on the arc; and these two lines will contain the angle required.

Case 2. When the angle contains more than 60 degrees. Suppose, for example, we wish to form an angle containing 148 degrees.

Describe the arc B C D, and make the transverse distance of 60 and 60 equal the radius as before. Take the transverse distance of $\frac{1}{2}$ or $\frac{1}{3}$, &c. of the given number of degrees, and lay this distance on the arc twice or thrice, as from B to *a*, *a* to *b*, and from *b* to D. Draw two lines connecting B to A, and A to D, and they will form the angle required.

When the required angle contains less than 5 degrees, suppose $3\frac{1}{2}$, it will be better to proceed thus.

With the given radius, and from the centre A, describe the arc D G; and from some point D lay off the chord of 60°, which suppose to give the point G, and also from the same point D, lay off in the same direction the chord of 56½ degrees ($=60°-3\frac{1}{2}°$), which would give the point E. Then through these two points, E and G, draw lines to the point A, and they will represent the angle of 3½ degrees as required.

From what has been said about the protracting of an angle to contain a given number of degrees, it will easily be seen how to find the degrees (or measure) of an angle already laid down.

LINE OF POLYGONS.

The line of polygons is chiefly useful for the ready division of the circumference of a circle into any number of equal parts from 4 to 12; that is, as a ready means to inscribe regular polygons of any given number of sides, from 4 to 12, within a given circle. To do which, set off the radius of the given circle (which is always equal to the side of an inscribed hexagon) as the transverse distance of 6 and 6, upon the line of polygons. Then the transverse distance of 4 and 4 will be the side of a square; the transverse

distance between 5 and 5, the side of a pentagon; between 7 and 7, the side of a heptagon; between 8 and 8, the side of an octagon; between 9 and 9, the side of a nonagon, &c., all of which is too plain to require an example.

If it be required to form a polygon, upon a given right line, set off the extent of the given line, as a transverse distance between the points upon the line of polygons, answering to the number of sides of which the polygon is to consist; as for a pentagon between 5 and 5; or for an octagon between 8 and 8; then the transverse distance between 6 and 6 will be the radius of a circle whose circumference would be divided by the given line into the number of sides required.

The line of polygons may likewise be used in describing, upon a given line, an isosceles triangle, whose angles at the base are each double that at the vertex. For, taking the given line between the compasses, open the sector, till that extent becomes the transverse distance of 10 and 10, then the transverse distance of 6 and 6 will be the length of each of the two equal sides of the isosceles triangle.

All such regular polygons, whose number of sides will exactly divide 360 (the number of degrees into

which all circles are supposed to be divided) without a remainder, may likewise be set off upon the circumference of a circle by the line of chords. Thus, take the radius of the circle between the compasses, and open the sector till that extent becomes the transverse distance between 60 and 60 upon the line of chords; then having divided 360 by the required number of sides, the transverse distance between the numbers of the quotient will be the side of the polygon required. Thus, for an octagon, take the distance between 45 and 45; and for a polygon of 36 sides, take the distance between 10 and 10, &c.

LINES OF SINES, TANGENTS, AND SECANTS.

Given the radius of a circle (suppose equal to two inches); required the sine and tangent of 28°.30′ *to that radius —*

Open the sector, so that the transverse distance of 90 and 90 on the sines, or of 45 and 45 on the tangents, may be equal to the given radius, viz. two inches; then will the transverse distance of 28°.30′, taken from the sines, be the length of that sine to the given radius; or if taken from the tangents, will be the length of that tangent to the given radius.

But if the secant of 28°.30′ *was required —*

Make the given radius of two inches a transverse distance of 0 and 0, at the beginning of the line of secants, and then take the transverse distance of the degrees wanted, viz. 28°.30′.

A tangent greater than 45 *degrees* (*suppose* 60) *is found thus:* —

Make the given radius, suppose two inches, a transverse distance to 45, and 45 at the beginning of the scale of upper tangents, and then the required degrees (60°) may be taken from the scale.

Given the length of the sine, tangent, or secant of any degrees to find the length of the radius to that sine, tangent, or secant.

Make the given length a transverse distance to its given degrees on its respective scale. Then,

If a sine	the transverse distance of	90 and 90 on the sines	will be the radius sought.
If a tangent under 45°		45 and 45 on the tangents	
If a tangent above 45°		45 and 45 on the upper tangents	
If a secant		0 and 0 on the secants	

To find the length of a versed sine to a given number of degrees, and a given radius.

Make the transverse distance of 90 and 90 on the sine, equal to the given radius.

Take the transverse distance of the complement of the sine of the given number of degrees.

If the given number of degrees is less than 90, subtract the complement of the sine from the radius, the remainder will be the versed sine.

If the given number of degrees are more than 90, add the complement of the sine to the radius, and the sum will be the versed sine.

To open the legs of a sector, so that the corresponding double scales of lines, chords, sines, tangents, may make each a right angle.

On the line of lines, make the lateral distance 10, a transverse distance between 8 on one leg, and 6 on the other leg.

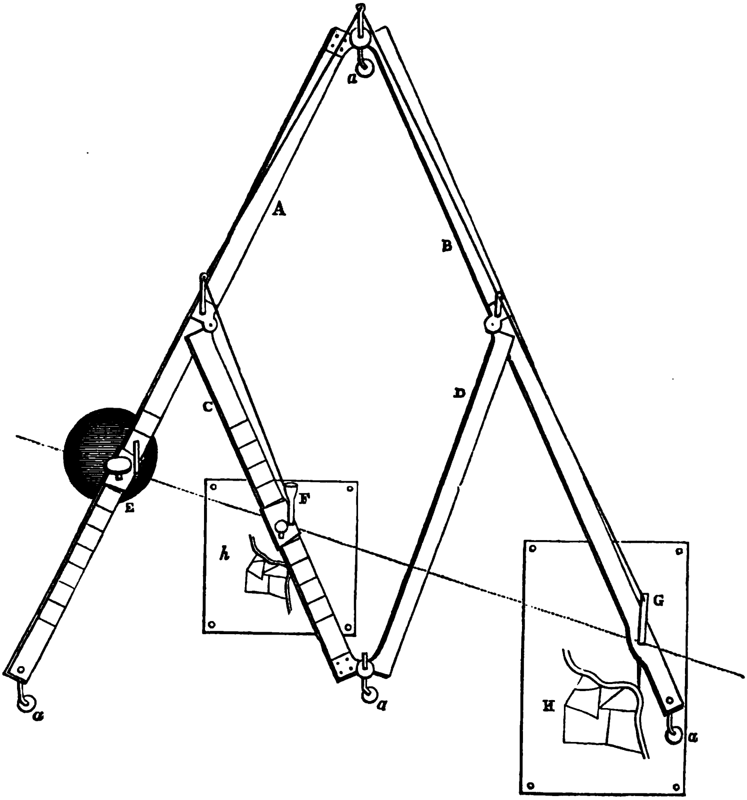
On the line of sines, make the lateral distance 90, a transverse distance from 45 to 45; or from 40 to 50; or from 30 to 60; or from the sine of any degrees to their complement.

On the line of tangents, make the lateral distance of 45, a transverse distance between 30 and 30.

THE PENTAGRAPH.

Having now gone through a description of the principal drawing instruments in every-day use, we shall close our task, by introducing an account of that valuable instrument used for the purpose of copying drawings, either upon the same scale, an enlarged scale, or a reduced scale, as may be required.

This instrument is represented in the annexed engraving, where it is shewn as in the act of copying



a plan H, upon a reduced scale *h*. The pentagraph consists of four rulers, A, B, C, and D, made of stout brass. The two longer rulers, A and B, are connected together by, and have a motion round a centre, shewn at the upper part of the engraving. The two shorter rulers are, in like manner, connected with

each other, and with the longer rulers, as may be clearly understood from an inspection of the engraving. The whole instrument is supported by small pillars resting upon ivory rollers, *a a a*, &c., which have a motion in all directions exactly like the brass castors fixed to ordinary tables. The rulers A and C have each an equal number of similar divisions, marked $\frac{1}{4}$, $\frac{1}{2}$, &c.; and likewise a sliding index, E and F, which can be fixed to any divisions on the ruler by a milled-headed clamp screw shewn in the engraving. The sliding indexes, E and F, have each of them a tube adapted to slide on a pin, rising from a heavy circular weight called the fulcrum, which acts as a centre for the whole instrument to turn upon when in use, or to receive a sliding holder with a pencil, or a tracing point, as may be required.

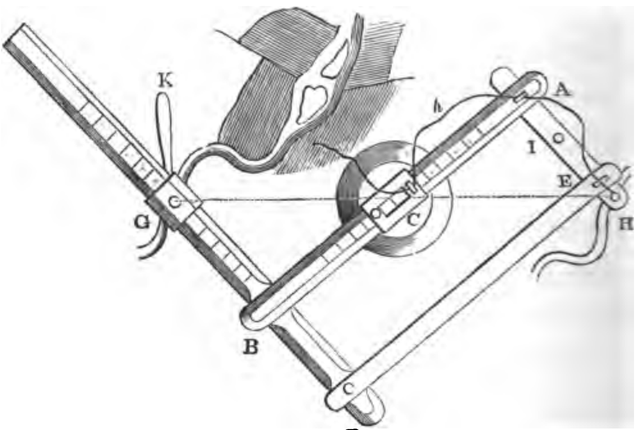
For explanation of the method of using the instrument, we will now turn to our engraving, which represents this instrument in the act of reducing a plan to a scale of $\frac{1}{2}$ the original. For this purpose the tracing point is fixed in a socket at G, over the original drawing H. The pencil is placed in a similar tube or socket at F, over the paper, to receive the copy; and the fulcrum is fixed to that at

E, the cale being one half the original. The sliding indices were first clamped at those divisions on the rulers marked $\frac{1}{2}$. The instrument being thus set for use, if correct, the three points, E, F, and G, will be in one straight line, as shewn by the dotted line in the figure. This will invariably be the case, at whatever division the indices may be set to. Now, if the tracing point G be passed delicately and steadily over every line of the plan H, a true copy, but of one half the scale of the original, will be marked by the pencil at F on the paper *h* beneath it. The fine thread represented as passing from the pencil quite round the further extremity of the instrument to the tracer at G, is to enable the draftsman at the tracing point to raise the pencil from the paper, whilst he passes the tracer from one part of the original to another, and prevents false lines being made on the copy. Likewise, it may be noticed, that the pencil holder F is represented as surmounted by a cup, which is for the purpose of putting some small shot in, to press the pencil heavier upon the paper, whenever such expedient may be found necessary.

If the object had been to enlarge the drawing to double its scale, then the tracer must have been

placed at F, and the pencil at G. And if a copy be required, retaining the scale of the original, then the slides E and F must be placed at the divisions marked 1. The fulcrum must take the middle station, and the pencil and tracer those on the exterior rules A and B of the instrument.

A scientific friend, about two years ago, drew our attention to a contrivance for a pentagraph, of which a description and engraving had been previously published in some periodical work. It is represented in the annexed figure, in the process of copy-



ing the survey of a river, &c. It consists of four rulers forming a parallelogram, connected together by moveable joints at A, B, D, and E. On the

ruler A B there is a brass slider C, which is connected with a heavy circular fulcrum by a cylindrical axis turning in a brass collar, of sufficient length to ensure a steady motion to the whole instrument. An opening in the slider carries a vernier, or index, for setting the fulcrum, at whatever division on the rule may be required, as $\frac{1}{2}$, $\frac{1}{3}$, &c. Another slider G is placed on the ruler D B, which must likewise be set to the proper division; this carries the tracing point, to be passed carefully over the lines of the original plan, by means of the handle K, whilst the pencil at H makes the required copy. A thread F is applied to raise the pencil from the paper, when necessary, to avoid making false lines on the plan. The pencil may also be loaded to cause it to produce lines of any required strength. When the machine is accurately set for working, a straight line, connecting the points G and H, will pass through the centre C.

The chief advantages said to be possessed by a pentagraph of this construction, are, that it requires no wheels or rollers to support it when at work; and also, that the centre of motion being always near the centre of the instrument, there is a probability of its working with greater accuracy than when the fulcrum

is placed, as in the former instrument, at one of the extremities. We have never seen an instrument of this construction, and therefore cannot give an opinion of our own on its merits.

The principle is the same for each instrument, viz. that as the opposite sides are parallel in any position, a line drawn, through G, C, and H, makes the triangles H A C and C B G similar, the like sides being in a constant ratio to one another in every position of the tracing point G; hence, the scale of the copy of any plan will always bear the same ratio to that of the original, as A C to C B, and when they are equal, as in our figure, the copy will be equal in magnitude to the original.

ON COPYING DRAWINGS EITHER TO THE SAME SCALE, BY REDUCTION, OR ENLARGEMENT.

It has been stated above, that the pentagraph affords the means of copying drawings, whether required of the same size (or scale), or to bear any other proportion to the original, as one half, one third, &c., or twice, thrice, &c. It is certainly a very valuable instrument for such a purpose; but, its dexterous use in copying very intricate drawings requires considerable care and skill, not so much in the accurately

setting of the slides to the proper divisions on the rulers, as in the management of the tracing and pencil points. For success in its use, the tracer must be passed along the lines, angles, and curves of the original drawing with extreme delicacy and steadiness of hand, otherwise the corresponding lines on the copy will be crooked when they ought to be straight; the angular points will not be well defined; and if there are in the original any parallel lines very close to each other, they will be so jumbled together in the copy, as to render it next to impossible to extricate them correctly, when permanently penning it in, after the work of the pentagraph is done. The beginner, however, need not be discouraged if the first or second attempt fails of answering his expectations, for the successful use of this instrument in copying very minute and complicated drawings, can only be attained by perseverance and experience.

There are also other modes of multiplying copies of an original production, a few of which we shall now mention as not irrelevant to the professed object of our book. The first, is by placing the original drawing upon the clean face of the paper intended for the copy, and having fixed it firmly by placing weights on the corners, or what is better, by means of

drawing pins as described at page 33.; and then with a needle point prick through the principal points, which being afterwards joined by drawing the necessary lines, will produce the copy required. This method, as well as that of using blacked paper, is more particularly described at page 32., where we have described the tracing point; we may, however, add to what is there stated, that the fine point of a porcupine's quill makes a tolerable good tracer.

Another method of copying, and which is sometimes resorted to when the original is of too much value to admit of being pricked through, is by the use of a large sheet of plate glass mounted in a frame, and set up at any convenient angle against a window, or where a strong light falls upon and shines through it; the drawing having been attached by pins or otherwise to the under side of the paper intended for the copy, is placed upon the glass, and by the strong light from behind the paper is rendered transparent, and a tracing may be made with great precision and ease.

The last method we shall mention is by means of squares; and with the aid of proportional compasses the most minute drawing, whether a map, an architectural design, or of mechanical engineering, may

be copied with great accuracy. This may, perhaps, be best shown by an example.

Fig. 1.

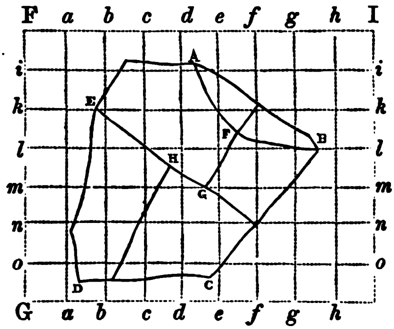
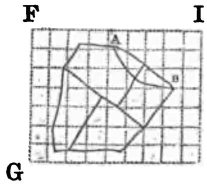


Figure 2.



Let figure 1. in the above engraving represent a plan of an estate which it is required to copy upon a reduced scale of one half; the copy will therefore be half the length, and half the breadth, consequently will occupy but one fourth of the space of the original. Our subject is a map of an estate, but the process would be precisely the same if it were an architectural, mechanical, or any other drawing.

First, draw the lines F I and F G at right angles to each other; then, from the point F towards I and

G, set off any number of equal parts, as F *a*, *a b*, *b c*, &c., on the line F I; and F *i*, *i k*, *k l*, &c., on the line F G; then, from the points on the line F I draw lines parallel to the other line F G as *a a*, *b b*, *c c*, &c., and from the points on F G draw lines parallel to F I, as *i i*, *k k*, *l l*, &c., which, being sufficiently extended towards G and I, the whole of the original drawing will be covered with a reticule of small but equally sized squares.

This done, draw upon the paper intended for the copy a similar set of squares, but having each side only one half the length of the former, as is represented in figure 2. It will now be evident, that if the lines of the plan A B, B C, C D, &c., figure 1., be drawn in the corresponding squares of figure 2., that a correct copy of the original will be produced, and of half the horizontal scale; thus, commencing at A, observe where, in the original, the angle A falls, which is towards the bottom of the square marked on the top *d e*; therefore, in the corresponding square of the copy, and in the same proportion towards the left hand side of it, which should be determined by the use of the proportional compasses, described at page 17., place the same point in the copy. From thence, finding by the proportional compasses the point on

the bottom line of that square, where the curved line A F crosses, which is about two fifths from the left hand corner towards the right, cross it similarly in the copy. Again, it crosses the right hand bottom corner of the second square below *d e*, therefore describe it so in the copy; and by means of the proportional compasses find the points where it crosses the lines *f f* and *g g*, above the line *l l* (by taking the distances of such crossings from the nearest corner of a square in the original, between the large points of the proportional compasses, and with the small points at their opposite end, set off the required crossing on the corresponding lines on the copy), then determine the place of the point B, in the third square below *g h* on the top line; and a line drawn from A in the copy, through these several points to B, will be a correct reduced copy of the original line.

Proceed in like manner with every other line on the plan, and its various details, and you will have the plot or drawing, laid down to a small scale, yet bearing all the proportions in itself exactly as the original. It may appear almost superfluous to remark, that the process of enlarging drawings by

means of squares is a similar operation to the above, except that the points are to be determined in the smaller squares of the original, and transferred to the larger squares of the copy. The process of enlarging, under any circumstances, does not admit of the same accuracy as that of reducing.

PRACTICAL HINTS, &c.

ON THE MANAGEMENT OF DRAWING PAPER.

The first thing to be done preparatory to the commencement of a drawing is the preparation of the paper, that is, the stretching it evenly upon the smooth and flat surface of a drawing board. The edges of the paper should first be cut straight, and, as near as possible, at right angles with each other; also the sheet should be so much larger than the intended drawing and its margin, as to admit of being afterwards cut from the board, leaving the border by which it is attached thereto by glue or paste, as we shall next explain.

The paper must first be thoroughly and equally damped with a sponge and clean water, on the opposite side from that on which the drawing is to be made. When the paper absorbs the water, which may be seen by the wetted side becoming dim, as its surface is viewed slantwise against the light, it is to be laid on the drawing board with the wetted side downwards, and placed so that its edges may be nearly parallel with those of the board; otherwise, in using a T

square, an inconvenience may be experienced. This done, lay a straight flat ruler on the paper, with its edge parallel to, and about half an inch from one of its edges. The ruler must now be held firm, while the said projecting half inch of paper be turned up along its edge; then, a piece of solid glue (common glue will answer the purpose), having its edge partially dissolved by holding it in boiling water for a few seconds, must be passed once or twice along the turned up edge of the paper, after which, by sliding the ruler over the glued border it will be again laid flat, and the rule being pressed down upon it, that edge of the paper will adhere to the board. If sufficient glue has been applied, the ruler may be removed directly, and the edge finally rubbed down by an ivory book knife, or any clean polished substance at hand, which will then firmly cement the paper to the board. This done, another but *adjoining* edge of the paper must be acted upon in like manner, and then the remaining edges in succession; we say the adjoining edges, because we have occasionally observed, that when the opposite and parallel edges have been laid down first, without continuing the process progressively round the board, a greater degree of care is required to prevent undulations in the paper as it dries.

Sometimes strong paste is used instead of glue; but as this takes a longer time to set, it is usual to wet the paper also on the upper surface to within an inch of the paste mark, care being taken not to rub or injure the surface in the process. The wetting of the paper in either case is done for the purpose of expanding it; and the edges being fixed to the board in its enlarged state, act as stretchers upon the paper, while it contracts in drying, which it should be allowed to do gradually. All creases or undulations by this means disappear from the surface, and it forms a smooth plane to receive the drawing.

TABLE OF THE DIMENSIONS OF DRAWING PAPER.

Demy,	20	Inches by	15¼	inches.
Medium,	22¾	„	17½	„
Royal,	24	„	19¼	„
Super Royal,	27¼	„	19¼	„
Imperial,	30	„	22	„
Elephant,	28	„	23	„
Columbier,	35	„	23½	„
Atlas,	34	„	26	„
Double Elephant,	40	„	7	„
Antiquarian,	53	„	31	„
Emperor,	68	„	48	„

MOUNTING PAPER AND DRAWINGS, VARNISHING, ETC.

In mounting paper upon canvas, the latter should be well stretched upon a smooth flat surface, being damped for that purpose, and its edges glued down, as was recommended in stretching drawing paper. Then with a brush spread strong paste upon the canvas, beating it in till the grain of the canvas be all filled up; for this, when dry, will prevent the canvas from shrinking when subsequently removed; then, having cut the edges of the paper straight, paste one side of every sheet, and lay them upon the canvas sheet by sheet overlapping each other a small quantity. If the drawing paper is strong, it is best to let every sheet lie five or six minutes after the paste is put on it; for, as the paste soaks in, the paper will stretch, and may be better spread smooth upon the canvas; whereas, if it be laid on before the paste has moistened the paper, it will stretch afterwards and rise in blisters when laid upon the canvas. The paper should not be cut off from its extended position till thoroughly dry, which should not be hastened, but left in a dry room to do so gradually if time permit; if not, it may be exposed to the sun, unless in the

winter season, when the help of a fire is necessary, provided it is not placed too near a scorching heat.

In joining two sheets of paper together by overlapping, it is necessary, in order to make a neat joint, to feather edge each sheet; this is done by carefully cutting with a knife, half way through the paper near the edges, and on the sides which are to overlap each other; then strip off a feather edged slip from each, which, if done dexterously, will form a very neat and efficient joint when put together.

The following method of mounting and varnishing drawings or prints, was communicated to us some years ago by Mr. Peacock, an artist of Dublin. Stretch a piece of linen on a frame, to which give a coat of isinglass or common size, paste the back of drawing, which leave to soak, and then lay it on the linen. When dry, give it at least four coats of well-made isinglass size, allowing it to dry between each coat. Take Canada balsam diluted with the best oil of turpentine, and with a clean brush give it a full flowing coat.

GENERAL RULES APPLICABLE IN ALL GEOMETRICAL CONSTRUCTIONS.

In selecting black lead pencils for use, it may be remarked that they ought not to be very soft, nor so

hard that their traces cannot be easily erased by the India rubber. Great care should be taken in the pencilling that an accurate outline be drawn; the pencil marks should be distinct, yet not heavy, and the use of the rubber should be avoided as much as possible, for its frequent application ruffles the surface of the paper, and will destroy the good effect of shading or colouring, if any is afterwards to be applied.

The following seven useful rules are taken from Mr. Thomas Bradley's valuable work on Practical Geometry:—

1. Arcs of circles, or right lines by which an important point is to be found, should never intersect each other very obliquely, or at an angle of less than 15 or 20 degrees; and if this cannot be avoided, some other proceeding should be had recourse to, to define the point more precisely.

2. When one arc of a circle is described, and a point in it is to be determined by the intersection of another arc, this latter need not be drawn at all, but only the point marked off on the first, as it is always desirable to avoid the drawing of unnecessary lines. The same observation applies to a point to be determined on one straight line by the intersection of another.

3. Whenever the compasses can be used in any part of a construction, or to construct the whole problem, they are to be preferred to the rule, unless the process is much more circuitous, or unless the first rule (above) forbids.

4. A right line should never be obtained by the prolongation of a very short one, unless some point in that prolongation is first found by some other means, especially in any essential part of a problem.

5. The larger the scale on which any problem, or any part of one, is constructed, the less liable is the result to error; hence all angles should be set off on the largest circles which circumstances will admit of being described, and the largest radius should be taken to describe the arcs by which a point is to be found through which a right line is to be drawn; and the greater attention is to be paid to this rule, in proportion as that step of the problem under consideration is conducive to the correctness of the final result.

6. All lines, perpendicular or parallel to another, should be drawn long enough at once, to obviate the necessity of producing them.

7. Whenever a line is required to be drawn to a point, in order to insure the coincidence of them, it is

better to commence the line from the point; and if the line is to pass through two points, before drawing it, the pencil should be moved along the rule, so as to ascertain whether the line will, when drawn, pass through them both. Thus, if several radii to a circle were required to pass through any number of points respectively, the lines should be begun from the centre of the circle; any error being more obvious when several lines meet in a point.

Table of Factors to facilitate Geometrical Constructions and Calculations relating to the Circle.

Let C = Circumference of a circle whose diameter is unity.
S = Sides of a square equal in area to it.
A = Area of the circle.

Then —

$C = 3.14159265$, &c.	$\frac{1}{360} C = 0.00872665.$
$2\ C = 6.28318531.$	$\frac{1}{C} = 0.31830989.$
$\frac{1}{2}\ C = 1.57079633.$	$\frac{1}{4C} = 0.07957747.$
$\frac{1}{4}\ C = 0.78539816.$	$\frac{2}{C} = 0.63661977.$
$\frac{2}{3}\ C = 2.09439510.$	$\frac{4}{C} = 1.27323954.$
$\frac{4}{3}\ C = 4.18879020.$	$C_2 = 9.86960440.$
$\frac{1}{6}\ C = 0.52359878.$	$\sqrt{C} = 1.77245385.$
$\frac{1}{8}\ C = 0.39269908.$	$\frac{360}{C} = 114.59155903.$
$\frac{1}{12}\ C = 0.26179939.$	$S = 0.88622692.$
$\frac{1}{24}\ C = 0.13089969.$	$A = 0.78539816.$

SOME USES OF THE FOREGOING TABLE IN CALCULATING AREAS.

To find the circumference of a circle when the diameter is given.

Rule.—Multiply the given diameter by the factor C, using any number of decimals that may be considered necessary; the product will be the circumference.

To find the diameter of a circle when the circumference is given.

Rule. — Divide the given circumference by the factor C, the quotient will be the diameter.

To find the area of a circle when the diameter is given.

Rule. — Multiply the square of the given diameter by the factor A, the product will be the area.

When the circumference is given.

Rule. — Multiply the square of the given circumference by the factor, $\frac{1}{4}$ C, the product will be the area.

When both circumference and diameter are given.

Rule. — Multiply the circumference by the diameter, and divide the product by 4; the result will be the area.

To find the length of any arc of a circle.

Rule. — From 8 times the chord of half the arc,

subtract the chord of the whole arc; one third of the remainder will be the length of the arc, nearly.

To find the area of a sector of a circle.

Rule. — Multiply the length of the arc by half the length of the radius, the product will be the area.

To find the area of a segment of a circle.

Rule.—To the chord of the whole arc, add the chord of half the arc, and one third of it more. Then multiply the sum by the versed sine, or height of the segment, and four tenths of the product will be the area.

To find the radius of a segment arch having the span and rise (or versed sine) given.

Rule. — Add together the square of half the span, and the square of the versed sine, and divide the sum by twice the versed sine; the product will be the radius required.

TABLE OF POLYGONS.

Names.	No. of Sides.	Radius of Circum-scribing Circle.	Factors for Sides.	Multiplyers for Areas.
Trigon (equilat. Triangle).	3	0.577350	1.732051	0.433013
Tetragon (or square) .	4	0.707107	1.414214	1.000000
Pentagon	5	0.850651	1.175570	1.720477
Hexagon	6	1.000000	1.000000	2.598076
Heptagon	7	1.152382	0.867767	3.633912
Octagon	8	1.306563	0.765367	4.828427
Nonagon	9	1.461902	0.684040	6.181824
Decagon	10	1.618034	0.618034	7.694209
Undecagon	11	1.774732	0.563465	9.365640
Dodecagon	12	1.931852	0.517638	11.196152

SOME USES OF THE FOREGOING TABLE.

A circle being given, and it is required to inscribe in it a regular polygon of any number of sides. Take, with a pair of compasses, from a scale, the unity of which is equal to the radius of the given circle, the distance, given in the column, headed "Factors for Sides," which distance will step round the circumference of the circle, as many times as the required polygon has sides; the points thus stepped, being connected with lines, will complete the polygon.

Upon a given line to describe a regular polygon.

Take from a scale, the unity of which is equal to the given line, the distance in the column headed "Radius of Circumscribing Circle," with which form an isosceles triangle upon the given line as a base: the vertex will be the centre of a circle circumscribing the required polygon, of which the given line is one side.

ARITHMETICAL RULES.

Given the side of a regular polygon of any number of sides; to find the radius of the circle in which it may be inscribed.

Rule.—Multiply the given side of the polygon by the number from the column, headed "Radius of

Circumscribing Circle;" the product will be the radius required.

Given the radius of a circle to find the length of the side of any regular polygon, which may be inscribed in it.

Rule. — Multiply the given radius by the number from the column, headed "Factors for Sides;" the product will be the length of the side required.

To find the area of a regular polygon having the length of a side given.

Rule. — Multiply the square of the given side by the number from the column headed "Multiplyers for Areas;" the product will be the area.

THE THEODOLITE.

Our useful little work, falling into the hands of students and others entering the profession as surveyors, it has been suggested that a desirable addition could be made by a description of an instrument previously but imperfectly described and known as the Theodolite, now so frequently in use. Mr. Castles has very liberally given permission to the making an extract, and to copy the engraving from his excellent work on Surveying *, which is as follows: —

The Theodolite is the most useful instrument that has been invented, for taking horizontal and vertical angles, as, by the nature of its construction, it is not necessary that, in the former, the objects should be in the same horizontal plane; or, in the latter, in the same vertical plane.

This instrument stands upon three legs, and consists of three divisions, and has three motions.

* A Treatise on Land Surveying and Levelling. By H. J. Castles, Esq., Surveyor and Civil Engineer. 8vo. 1842.

1st. — *The absolute horizontal motion* of the whole instrument moving upon its axis, with clamp-screw (C) to fix it, and tangent-screw (T) for fine adjustment.

2d. — *The relative motion* (as to the lower) of the *upper* of the two horizontal circles, to which the vernier (V) is attached, with its clamp-screw (*c*), and adjusting-screw (*t*).

These two motions are for taking horizontal angles.

3d. — The relative motion of the vertical circle, which has also, as well as the other two, its clamp-screw (*c*), and fine adjusting-screw (*i*).

Detail of the first motion, which must be perfectly horizontal.

The lower (K) of the two parallel *Plates* is screwed tightly down to the legs of the instrument. The axis of the whole instrument passes right through to this plate. The centering, at the other end, is fixed to the upper of the two parallel *circles* — the upper one, called the *vernier circle,* from having the vernier attached to it; the lower, the graduated or horizontal limb (L), having its whole circumference graduated into degrees and half degrees. The lower circle has a distinct motion from

the upper, working by means of a collar attached to it, upon the centering of the upper. Upon this is again fixed the collar (D) of the large clamp-screw (of the first division), which is attached as well as the tangent-screw to the upper of the parallel plates, which, connected with a ball works in the socket of the lower plate, and has a double relative motion.

The upper of the parallel *plates* is made *instrumentally* parallel to the lower graduated circle; and the upper circle (when in correct adjustment) is also parallel to them both.

Upon the upper of these circles are two small spirit levels, B, D, at right angles to each other.

By means of two pairs of conjugate screws (PPP), which alter the relative position of the plates, the upper one can be always made level, as will be immediately seen, by the two bubbles, in the levels, being in the centre of the tube; and, once set level, the instrument, when in adjustment, will be level in any position.

By tightening the clamp-collar, and using the tangent-screw, the finest adjustment can be obtained.

The second motion. — Unclamp the horizontal circles, and the upper will move independently of the

lower, or body of the instrument, with which it is connected. This motion of the upper circle, or vernier plate, as well as that of the two (or virtually the motion of the lower), will be perfectly level, if the instrument be correct and in adjustment; and the bubbles now, as then, will be, in every position, in the centre of the tubes. This is, however, the weakest part of the instrument. The upper circle is very thin, and having an unequal and constant pressure exerted in one place, the bubbles, which, when the two circles are clamped together, are in perfect adjustment, are often very far from being so, when the upper plate is no longer held down by the clamp-screw (*c*).

The clamp (*c*), and tangent-screw (*t*), are placed alongside these circles, and have the same office as those of the first motion.

The third motion. — In this, which is a vertical motion, a graduated circle (N) is made to move instrumentally at right angles, with the horizontal motion plane of the instrument.

This circle moves upon its axis (A), which, passing through the common centre of the instrument, is supported by two shoulders or supports (FFP), at

right angles with the vernier plate, to which this axis is made parallel.

This, like the horizontal circle, is graduated to half degrees, and, like that, by means of a vernier (*v*), supported by the compass box, is capable of being read off to minutes.

Attached to this vertical arc, above it, is placed a telescope, supported on two Ys or arms, in the form of the letter Y. These Ys are virtually tangents to the tube of the telescope, which is generally furnished with bell-metal collars, ground truly cylindrical, to rest upon them. These are kept in by clips (*d e*), fastened by a pin.

A long spirit-level (*b*) is fixed beneath, to the telescope, parallel to it. The upper part of the inside of the tube is ground truly circular, so that when it is nearly filled with alcohol, or any other spirit, and its axis in a level position, the fluid may recede from the centre, which will then be its upper part.

There is also a compass box (G), with a magnetic needle. This box is generally placed over the two circular plates, and under the vertical arc. It is occasionally used to find the bearing of any line, though it is not correct enough for that purpose. It is really only calculated for ascertaining, *roughly*, the

general position, as to the north and south points of the estate.

The Working of the Theodolite.

Adjust, first, the parallel screws (PP), so as to have, as nearly equal lengths of the worm, as possible, above the upper plate.

Extend the three legs, approaching or extending each, until the bubbles in the two levels (B B) are nearly central, and the plummet, suspended from a hook under the body of the instrument, hangs freely above the centre of the station. The better plan is to move only one leg, which is, of itself, capable of a double motion.

Press the legs firmly in the ground, unclamp the *whole* instrument by means of the large clamp-screw (C,) observing to keep the other motions clamped.

It must now be remembered, that the two levels, on the horizontal plate, are conjugate, *i. e.* at right angles; and, that the opposite screws, also, are conjugate, each pair of them.

Set one level in a plane, vertically parallel to a plane, passing through any one of the screws; and the other level and the other pair of screws, will be also in parallel vertical planes, conjugate to the former.

If both the bubbles of the levels, thus placed, are not in the centre, take the bubble that is not level, and, loosening one of the corresponding conjugate screws, tighten the other, until the bubble be accurately adjusted. Then loosen and tighten the other pair in the same way, till the same result be obtained. This will probably throw the first out; repeat the process to each, until both bubbles are level.

Having these plates (K k) level, clamp the whole instrument, and, unclamping the parallel circles, set the broad arrow of the vernier, which is in the upper plate, to 360°, or zero, of the larger circle, and clamp it. This must be done by the magnifying or reading glass (*m*), attached to the horizontal circles.

This large circle is divided into 360, and then again, subdivided into half degrees, which are numbered from left to right, and by means of the vernier, read off to minutes.

Again, unclamp the large clamp-screw, and turn the whole instrument towards the left of the stations, between which, you are desirous of taking the angle, until you can cut the object as accurately with the intersection of the cross wires of the telescope, as can be done by the hand. Clamp the screw (C), and

slowly turning the milled-head tangent-screw (T), you can obtain all possible degree of accuracy.

Now, as the zero points of both upper and lower circles are together in the present position of the telescope, and as the lower circle is graduated from left to right, by separating the upper circle, and turning it round, till the centre of the cross wires of the telescope, which is attached to it, cut exactly the centre of the object at the second station, you obtain the angle between the two, determined by the position of the vernier and the length of the arc of the circle it has described. This can at once be read off from the plate by the broad arrow of the vernier, which will stand exactly above the number of degrees and minutes of the angle, measured between the two given objects.

When the cross wires, therefore, nearly cover the object, clamp the plates, and use the tangent-screw (*t*); and, with the magnifying glass (*m*), read off the angle, by means of the vernier. (For a description of the vernier, see page 107.)

The angle, thus read off, should always, if great accuracy be required, be read off by each of the two verniers. The common five-inch theodolite is furnished with two, and the larger instruments have

three, equi-distant from each other, so that the *mean* of the readings, taken at different points on the circumference, should correct the errors of eccentricity or graduation.

In extensive surveys, other securities are adopted against these errors.

Instead of fixing the broad arrow of the vernier at the zero point of the horizontal limb, at starting, the telescope is directed to the first station, with the broad arrow indifferently placed upon the lower plate, and its position carefully read off by the several verniers, and the *mean* taken. The difference between this mean, and that of the reading of the second station, is the measure of the required angle.

In incorrect graduation, this is perhaps the best check that can be used.

As an additional check, these angles are often repeated; that is — the angle is not taken again, by separating the upper plate and bringing the vernier back to zero, and then taking it a second time—but, without detaching the two plates after the last observation, turning the whole instrument bodily round to the first station, and then unclamping the vernier plate, and turning it round to the second station.

The difference between this and the first reading,

before starting, will be double the mean angle. Keep the two plates still together, and turn the whole round, repeating the process as before.

The difference between this third reading, and the reading at starting, will be three times the angle required.

It is requisite that the verniers should be separately marked, as A, B, C.

TO TAKE A VERTICAL ANGLE, OR AN ANGLE OF ELEVATION OR DEPRESSION.

First set the whole instrument level, as was explained before, by means of the bubbles on the vernier plate. Then bring the bubble of the telescope level (*b*) to the centre of the tube, observing whether, at the same time, the zero point of the circular arc coincides with the zero of the vernier. This must be carefully examined by the microscope.

The instrument being thus perfectly level, when the zero point of the circle and the broad arrow are together, raise or depress the telescope, till you distinctly cut the required object with the horizontal wire, or the common intersection of the three wires. The changed relative position of the broad arrow will give the required angle, which will be an angle

of depression, if the broad arrow be found between the zero of the plate and the object-glass of the telescope, and of elevation, if beyond them.

It will be requisite, for particular accuracy, to invert the telescope in its Ys, and read off the same angle from the other end; half the difference of these two will be the angle of error, of the vernier.

ADJUSTMENTS.

THE TELESCOPE.

The accuracy of this instrument, in its application to the purpose of taking angles, depends altogether upon the correctness of the line of collimation. The optical axis of the telescope, which is an imaginary line, joining the centre of the object-glass and eye-glass, should pass through the point of intersection of the cross wires.

These wires are attached to a broad flange of an inner tube, within the tube of the telescope, near the eye-piece, with which it is connected by two pairs of conjugate capstan-headed screws (*a a a*), so as to admit of a double relative motion.

I.—TO ASCERTAIN, WHETHER THE LINE OF COLLIMATION IS IN ADJUSTMENT.

Place the telescope within the Ys, and, having found some point clearly defined, which is cut by the intersection of the cross wires, turn the telescope round on its axis, and observe, whether, during its whole revolution, the centre of the wires remains the same, always covering the same point. If it does, it is in adjustment; if not, turn the telescope round on its axis, and correct for half the error, by means of the small capstan-headed screws (*a a a*), loosening one and tightening the other.

II.—WHETHER THE AXIS OF THE LEVEL IS PARALLEL TO THE AXIS OF THE TELESCOPE.

Place the telescope on the Ys, and unclamping the large clamp-screw, set the telescope over one pair of conjugate screws, and loosen and tighten them till the level, attached to the telescope, is made perfectly level; or it may be made perfectly level by the vertical tangent-screw.

Then reverse the telescope in the Ys, if the level remains the same, this also is in adjustment; if not, correct for one half the error by the capstan-headed

adjusting-screw, at the end of the level (S); and the other half by the vertical tangent-screw.

There is also a side adjustment required.

The level may not always be immediately under the telescope, but a little to the right or to the left; this must not affect the position of the bubbles, or a lateral adjustment, similar to the vertical one, is indispensable, by means of the capstan-headed screw, at the other end of the level (S).

III. — HORIZONTAL.

To make the axis of the bubble on the vernier plate parallel to that plate.

Let one bubble be over one pair of the circular plate screws, then the other bubble will be over the conjugate pair; make both bubbles level, turn them half round the circumference, and if the bubbles deviate from the centre, correct one half the error, by the small milled-headed screws above the levels; and the other half error, by the circular plate screws: repeat this, till the bubbles are level, in every position, throughout a whole revolution of the circumference.

IV.—HORIZONTAL.

Whether, after having duly corrected for the third adjustment, or made the "axis of the bubbles, on the vernier plate, parallel to that plate," the bubbles will remain perfectly level, during a whole revolution of the instrument upon the common axis.

Clamp the two circular plates, and unclamp the large clamp-screw; set the bubbles perfectly level, as before; when, immediately over each pair of conjugate-screws, reverse them; if they continue level, they are in adjustment; if not, the two circular plates are moving upon different axis, and are not parallel to each other. This imperfection can only be well remedied by an instrument maker.

V.—VERTICAL.

Whether the vertical arc moves in a truly vertical plane.

Set the vertical plate, or upper horizontal circle, perfectly level.

Direct the telescope to some well-defined angle of a building; or, should there be no building convenient, suspend a string, with a plummet attached, from the top of a high pole, and, taking care that the

intersection of the wires exactly cut the string, near the plummet, raise the vertical arc, observing whether the cross wires, throughout the whole of the vertical motion of the telescope, cover the vertical string; if it does, this also is in adjustment.

As it is seldom found that two objects, whose horizontal angle is required, are exactly in the same horizontal plane, this adjustment becomes a very important one, and requires great care. Considerable error has resulted from neglect of it.

VI.—VERTICAL.

Whether the vertical vernier is in adjustment, or perfectly central.

Direct the telescope to some point of elevation, and note the angle. Reverse the telescope in its Ys, and raising the telescope to the same object, read off the same angle; if these angles are the same, the vernier is in adjustment; if not, correct the vernier for the error, by means of the small screw, fastening the vernier to the vertical plate, which can be loosened, and half the difference of these two angles will be the angle of error; or, which is better, add this angle of error to every angle of elevation, when you use the end that reads off the smaller angle, and subtract

the same, from that of depression, under the same circumstances.

When you read with the larger angle, subtract this angle of error from the angle of elevation, and add it for the angle of depression.

PARALLAX

Is an error occasioned by the focus of the eye-glass not being at once, with the focus of the object-glass, in the field of the cross wires.

The existence of parallax is determined by moving the eye about, when looking through the telescope, observing whether the cross wires change their position, and are flittering and undefined.

To correct this error, first adjust the eye-glass, by means of the moveable eye-glass tube, till you can perceive the cross wire clearly defined, and sharply marked against any white object.

Then, by moving the milled-head screw (M), at the object-end of the telescope, until you obtain the proper focus, according to the distance of the object, you are enabled at once to see clearly the object, and the intersection of the wires, clearly and sharply defined before it.

The existence of parallax is very inconvenient, and

where disregarded, has frequently been productive of serious error. It will not always be found sufficient to set the eye-glass first, and the object-glass afterwards. The setting of the object-glass, by introducing more distant rays of light, will affect the focus of the eye-glass, and produce parallax or indistinctness of the wires, when there was none before. The eye-piece must, in this case, be adjusted again.

Generally, when once set for the day, there is no occasion for altering the *eye-glass*, but the *object-glass* will, of course, have to be altered at every change of distance of the object.

THE VERNIER.

The vernier is a contrivance for subdividing, to any extent, the smallest division in a graduated scale, varying according to the scale to be subdivided, and the extent of subdivision, but having the same principle in all cases.

The following explanation of that of the 5-inch theodolite of Simms, which is given in the plate, and which is a very convenient and accurate little instrument, will serve for all.

In this, the lower circle is divided into half degrees,

or 30 minutes; and the vernier so arranged as to read off to one minute.

Twenty-nine divisions of the graduated scale, which is twenty-nine half degrees of the lower circle, are taken; and are divided, upon the vernier, into thirty divisions: now, as thirty divisions are compressed into the space of twenty-nine, each of these thirty divisions is one-thirtieth less than those of the twenty-nine: or, as the whole arc, in the graduated scale, is equal to 29 half degrees, or 870 minutes, and these are subdivided into 30 divisions, in the vernier scale, each of these subdivisions is equal to 29 minutes — therefore, if the zero point of the limb correspond to the broad arrow of the vernier, the first division line of the vernier is one minute to the right of the corresponding division on the limb; the second division on the vernier, two minutes to the right; the third, three minutes; and, so on, till the thirty divisions of the vernier, exactly coinciding with the twenty-ninth division, is just 30 minutes to the right of the thirtieth, or corresponding division in the limb, and therefore corresponds to the twenty-ninth division.

If the vernier, therefore, be moved, till its first division corresponds to the first division of the limb, the broad arrow of the vernier will be removed one

minute from the zero of the limb. If the second division of the vernier be made to correspond with the second division of the limb, the broad arrow of the vernier will be two minutes removed from the zero of the limb. If the third corresponding divisions coincide, the zero's are three minutes removed, and so on.

Hence, *to set the instrument* at any angle, of any number of minutes, between 0 and 30, and 30 and 60, move the vernier, until the broad arrow becomes in such a position, *within the required half degree*, as, that the number of the line, on the vernier, coinciding with the same numbered line on the limb, shall correspond to the number of minutes required. And, to *ascertain the number of degrees and minutes* that there are in a given angle, observe where the broad arrow of the vernier is; if between a full degree and a half degree, so many degrees and as many minutes, as are denoted by the number of the first division line of the vernier, (reading onwards as the degrees number,) that coincides with the corresponding division in the limb; or, if between a half degree and a whole one, so many degrees and 30 minutes, *plus* the broken number of minutes, as denoted by the coincidence of the corresponding lines of the vernier and limb.

The principle of the above subdivision of the vernier of Simms's theodolite is very simple, and is universally applicable to any subdivision; viz., divide the value of the division, in the graduated scale, by the number of divisions in the vernier, and the quotient will be the value of each of these subdivisions.

Thus, in the theodolite the graduated division is 30 minutes; the number of vernier divisions 30; the instrument (29 being subdivided into 30) reads to one minute.

In the sextant, the graduated division is 10 minutes, or 600 seconds; the vernier subdivisions are 60; the reading of the instrument is to 10 seconds (59 of these 10 minutes are subdivided into 60).

In the circumferentor, in this country, the common graduation of the plate is to one degree, or 60 minutes; the vernier subdivisions are 20, making the reading of the instrument only 3 seconds, (19 of these divisions being subdivided into 20); in this case, nine and a half on each side of the zero being divided into 10.

Hence, the value of the graduated division being given, and the extent of subdivision of reading required, to ascertain the number of requisite subdivisions.

By the rule above, where $x+1=$ the required

number of the subdivisions in the vernier, and x that of the graduated arc; V, the value of the graduated division; and v, that of the required subdivision, we have

$$\frac{V}{x+1}=v, \text{ or } x=\frac{V-v}{v}$$

thus in the sextant V=10 minutes or 600 seconds; v=10 seconds

$$x=\frac{600-10}{10}=\frac{590}{10}=59 \text{ divisions.}$$

Again, if, in the circumferentor, V=1 degree or 60 minutes; and v= 3 minutes,

$x=\frac{60-3}{3}=\frac{57}{3}=$ 19 divisions of the plate, to be subdivided into $x+1$, or 20.

REMARKS ON LEVELLING,

AND

THE INSTRUMENTS USED FOR THAT OPERATION.

THE various kinds of instruments used in levelling have been so well and so repeatedly described, that I shall intrude upon the patience of the reader only a single remark on the choice of a level. Whatever may be the respective merits of the Y level, Troughton's improved, and the Dumpy, let him rest assured that if he has well learnt his business he may level to a high degree of accuracy with either. They each require the same care in perfecting the adjustments, and the same steady and constant attention to minutiæ in the actual use of them in the field. Nevertheless there is just so much difference between the three kinds of instrument, and particularly in the modes of adjustment, that I would recommend no practical man who has acquired experience in the use

of any one kind of level to change it for another in the hope of abridging his labours. Then with respect to those who have yet to choose an instrument, and to whom one is as rare and novel as another, I would say, if you want an instrument which is light to carry, and at the same time safe and steady in its adjustments, take Troughton and Simms' improved 14-inch level. If you do not object to the labour of carrying a much heavier instrument, and wish to be able to read your staff at a somewhat greater distance, you may take the Dumpy level or Troughton's improved 20-inch.

Having made choice of an instrument, the next thing to be attended to is the method of using it; and here again I shall not waste the time of the reader or myself by wading through what may be called the technical part of the subject, that is, the description of the instrument, and the methods of adjusting it, as this has been already fully and ably treated in a number of useful works devoted to the subject of practical geodesy. On the contrary, I shall proceed at once to the business of the field, supposing the reader who consults this appendix to have already made himself familiar with the various parts of the instrument, and with the mode of adjustment.

I shall further suppose the reader to be aware of what is meant by corrections for the curvature of the earth and for terrestrial refraction. To know that where the distance between the staff and the place of the instrument is considerable, a small *deduction* should be made from the reading of the staff to allow for curvature, and a still smaller *addition* should be made to allow for refraction; so that supposing no correction whatever to be made, the error caused by curvature is to a small extent neutralised, or rather diminished, by the error introduced by refraction. All this acquaintance with the *theory* of levelling I suppose the reader to possess, and at the same time give him credit for having discovered that in actual practice no corrections are made either for curvature or refraction. Lastly, I presume that he is aware of the nature of instrumental parallax and is careful to adjust the instrument* for distinct vision before attempting to read off the height of an object through the telescope of his level.

* For some excellent observations on this subject, and on the best mode of adjusting for distinct vision, the reader may consult Mr. Simms's "Treatise on Levelling," p. 20.

APPLICATION OF THE SPIRIT LEVEL.

The most obvious and simple purpose to which any levelling instrument can be applied is that of finding the difference of level between two given points. Now, in order to effect this, the contrivance which the instrument-maker puts into the hands of the engineer is an apparatus which enables him to fix the tube of a telescope from 10 to 24 inches in length into a perfectly horizontal position. When an observer looks through this telescope, therefore, he looks in a horizontal line, and the fine wire drawn from the spider's web, and fixed with the nicest precision at right angles to and cutting the axis of the telescope, will of course only coincide with a point or with another line on the same exact level as itself.

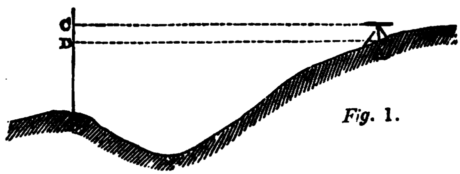


Fig. 1.

Suppose a level (*fig.* 1.), with its telescope adjusted to a horizontal position, to be planted at the point A for the purpose of ascertaining its height above B. The telescope being, as we have said, perfectly level, will of course neither look downwards nor upwards, but

only horizontally, and therefore it becomes necessary to introduce a staff or graduated pole to be held on the point B, in order that a height may be found exactly on the same level as the tube of the telescope. Let this height be C B, and then if we deduct from this the height (C D) of the telescope above the point A, we shall have the remainder D B equal to the difference of level between B and A.

This, then, is the most simple case of levelling. Plant the instrument on a given point A, adjust it to a horizontal position, and read off the height of a staff placed on another point B, that is, the height cut by the horizontal wire of the telescope. From this height deduct the height of the axis of the tube above the point A; the remainder is equal to the difference of level between the two points A and B.

For example, let the height of the axis of the telescope above the point A be 4 feet, and suppose the horizontal wire is observed to coincide with a point C, which is 14 feet above B; then $14 - 4 = 10$ feet, the difference of level between A and B.

Now this is one way of ascertaining the difference of level between two given points, and it would be a good way, supposing it were possible to measure at once with facility and with mathematical accuracy.

the height of the axis of the telescope above the ground. But as this is not easily done, the process above described, which requires the height of the telescope to be ascertained, is seldom resorted to in practice, the following expedient being attended with equal accuracy, and being performed with much greater facility.

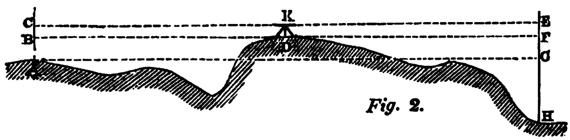


Fig. 2.

Let A and H (*fig.* 2.) be two points whose difference of level is required. Plant the instrument at D, and adjust it to a horizontal position. Read off A C, the height of a staff held at A, then turn the telescope round and read off E H, the height of a similar staff, or of the same staff held at H. Now deduct the smaller height A C or E G from the greater height E H, and the remainder G H is evidently the difference of level between A and H. Let us now revert to the first example, and examine what analogy this new process bears to the one there described. It is clear, according to that first example, that A B is the difference of level between D, the place of the instrument and the point A, and that F H is the difference

of level between the same spot D and the point H. Now deduct A B from F H, and the remainder is G H, the difference of level between A and H as before. It will be observed that, in this latter case, a double process has been performed. The height of D above A has first been found by observation and subtraction; the height of D above H has been found in a similar manner; and, thirdly, the lesser of these heights has been subtracted from the greater, in order to find the real and required difference between A and H. It is no wonder, therefore, that in practice, the much readier and shorter process illustrated by the simple deduction of A C from E H should supersede the more tedious process described in the first example. The analogy between the two methods will be rendered still more obvious than it has hitherto appeared, by rejecting the consideration of the point D. Thus A C is the height of K, the axis of the telescope above the point A, and E H is the height of K above another point H; it is clear that $EH - AC = GH$, the difference of level between A and H as before.

It will be observed that in thus illustrating from the most simple principles the *modus operandi* which prevails in all levelling operations, I have only

shown in the diagrams which have been referred to one single case of relative heights, namely, the case in which the place of the instrument is higher than either of the points whose relative level is to be determined. Let any other case be conceived, however, such as that in which the place of the instrument is higher than one of the points only, and lower than the other, or where again it is lower than both, and the same simple deductions still obtain; and in the same simple manner may the student elucidate for himself, either by diagram or calculation, the single and important principle on which the actual working process of levelling depends. This principle may be thus announced in general terms, that where any two points are observed to be any two separate heights below a common point, their difference of level is equal to the difference of such two separate heights.

The common point here is the axis of the levelling telescope — the two heights are the readings of the staff placed on each of the points whose relative level it is required to determine.

Having thus minutely explained the method of arriving by the spirit level at the difference of level between two given points, let us pause for a moment

to remark on the vast utility and importance of this single application of its power. In every department of hydraulics, in every operation of drainage and irrigation, the chief, and, generally speaking, the earliest consideration involves the necessity of determining this difference of level.

Then again, in all those mighty works of art with which, at a certain stage of civilisation, man covers the earth, causing all imaginary varieties of matter to assume new forms — rearing from out the hidden quarry of the mountain the stately fabric of his cities — disputing with nature the wild irregularity of her features — here throwing down precipices, and there exalting vallies, — in a word, in all those works which have ever exercised the skill and called forth the genius of the engineer or the architect, we shall find it indispensable that he should possess the means of determining with accuracy the difference of level between two given points. We may notice also, as scarcely of less consequence in a practical point of view, the converse of this case, or that in which it is sought to determine a point which shall be a given height or depth above or below some other point. The application of the spirit level to this latter purpose is so obvious from what has been

already explained, that we may safely leave it to the ingenuity of the most inexperienced reader.

LEVELLING FOR SECTIONS.

When it is required to show the figure of a country in profile, that is, the relative height of each part of a line traced upon it in any direction, the spirit level comes into constant and almost exclusive request. It is true there have been many attempts to determine a series of heights by other means, — as by the water level, by the agency of the plummet, by an instrument termed a reflecting level, by the theodolite, and other instruments for taking vertical angles, by the barometer, and by Dr. Wollaston's principle of ascertaining the temperature of boiling water for different altitudes; to each of these, however, as applied to the actual purpose of determining successive differences of level there is some great and serious objection, which renders it almost perfectly useless in comparison with the spirit level, and especially so when applied to those delicate operations in which the latter is found to perform with such nice and really astonishing accuracy. We proceed, therefore, at once to show the application of the spirit level to this purpose.

Let a, b, c, d, &c. (fig. 3.) be the surface of a country which we must suppose to have been already levelled and laid down upon paper, and we shall use this for illustrating the process which has already been gone through before transferring it to the paper.

Commencing at a, let us suppose that the first variation in the regular slope of the surface is at b, or let us suppose that b is a convenient distance from a, and that it is required to determine its height with reference to a. We have already seen that in such a case as this it is only necessary to plant the level somewhere between the two points, and read off the height on a staff which is on the same level as the axis of the levelling telescope; and we know that the difference between these two heights is the difference of level required between a and b. Suppose the next variation of ground to be at c, then the next operation will be that of determining the rise from b to c. In order to do this, plant the level between these two points, and read off as before, the separate heights of the axis of the telescope above the points b and c. Proceed in the same way between c and d, between d and e, and so on as far as may be required. Now it is evident that by a repetition of the process taught with respect to two points only, namely, the deduction of the less from the greater height, we ob-

tain in each case the difference of level between the successive points at which we suppose the staff to have been held. Also by adding the rise from *c* to *b* to the rise from *a* to *b*, we obtain the whole rise from *a* to *c*, and by adding to this again the rise from *c* to *d*, we obtain the whole rise from *a* to *d*, and so on. Further; suppose we have reached the top of the hill and have ascertained the whole rise from *a* to *k*, and ascertained the amount of fall from *k* to *l*, it is clear that this fall must be deducted from the whole rise up to *k*, to ascertain the rise from *a* to *l*.

It is on this principle that the separate elevations of each point in the surface are determined, all with reference to some fixed level. Now this fixed level may either be *a*, the point of commencement, or it may be some point real or imaginary, 100, or 200, or any other number of feet below *a*: in any case the fixed level is technically called the *datum*, the thing given, and a line drawn at the level of this *datum point* is called the *datum line*.

Such is the general principle on which levelling operations are conducted, when intended to be used for showing the section or profile of a country. From the explanation here given, it will appear that some system is necessary for registering the succes-

sive heights read off on the staff at the several points *a, b, c*; and it may also be stated, that there are a number of practical details to be attended to, which will much shorten the labours of the leveller, and without which, indeed, he would find it impossible to apply his observations to any useful purpose.

Referring to the diagram (fig. 3.), we have already explained that A A is called the Datum Line. It may further be added, for the purpose of rendering the future observations more intelligible, that the staff held at *a* is called the *Back Staff*, and that

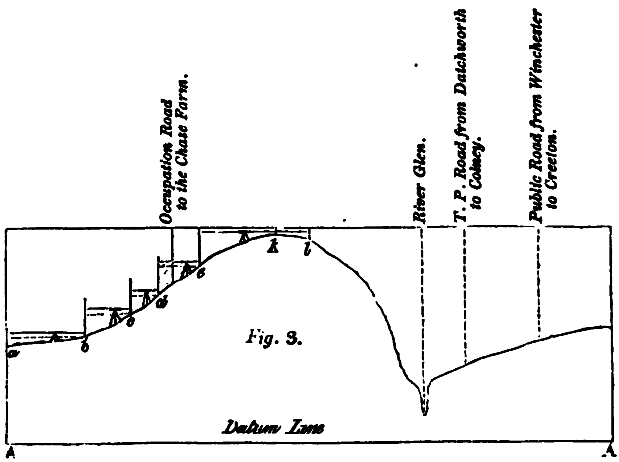


Fig. 3.

held at *b* is called the *Fore Staff*, when being read off in the first position of the instrument, that is, when the instrument is placed between *a* and *b*. Also, when the instrument is carried on beyond *b*,

and planted somewhere between *b* and *c*, the staff at *b* becomes the back staff, and the observation read off at *b* is the *back* observation; and the staff at *c* is the *fore* staff. Again, when the instrument is removed to a point beyond *c*, so as to look *back* to the staff at *c*, that in its turn becomes the *back* staff, while *d* is the *fore* staff; and so on.

Connected with such works as roads, canals, and railways, several kinds of section are essential at different stages of their progress, and for the different purposes of designing, laying them out, and arriving at an estimate of their cost.

A *trial section* is one made from levels taken over a line not definitively fixed, and not laid on a correct field plan. In this country, the published maps of the Ordnance Survey are commonly used for the purposes of trial sections. The engineer, guided by the best acquaintance he possesses with the physical features of the country, such as the mutual relations of its plains, summits, valleys, and rivers, bearing in mind the demands of commerce, and having regard to the local influence of manufactures, towns, and population, lays down on the Ordnance Maps of the district the line which appears most suited to the object in view. The levels taken over such a line

are sometimes plotted according to measurements taken from the Ordnance Map itself, and not according to distances actually measured on the ground. In this case, the section is necessarily very imperfect, and does not show, with any great fidelity, the actual contour of the country, because it is impossible to identify on the Ordnance Map any but the main features, such as the hills, valleys, rivers, roads, and principal buildings in the course of the line. The plotted distances are also usually much distorted in consequence of the necessary enlargement of the scale to a proper size for working purposes. Having had experience of many serious errors in the choice of lines in consequence of too great reliance on trial levels of this kind, we venture to protest very earnestly against the use of them for any important purpose. By a thoroughly skilled and experienced leveller, trial levels may be taken with distances measured on the ground in nearly the same time as those last described, and when laid down, they afford every requisite for deciding the comparative merits of different lines; and if taken as they ought to be, may even be used for the measurement of quantities, and for the general purposes of the estimate.

It appears to be not generally known amongst

levellers that, by adopting a proper system of ranging for trial sections, the Ordnance Maps may be depended on to a high degree of accuracy, and that such levels may be taken with scarcely any perceptible deviation from the exact line laid down.

It will not do, however, to set off and fix the line by means of such objects as the bends of streams and by measurements from isolated buildings, corners of roads, &c. Such a line will rarely be found correct, and will probably have awkward curves where it should be straight, and *vice versâ*, simply because minor points are not laid down on the Ordnance Maps from actual survey, but are merely sketched, and therefore are not to be depended on as to form and position.

The only system of ranging that will answer effectually with the Ordnance Maps is that which makes use of distant objects and relies upon their bearings, and that which the line makes with the Magnetic Meridian. It is an excellent method to rule on the Ordance Map faint parallel lines at an angle of about 24 degrees west of the axis or sides of the map, and using such lines for meridians, measure and note before going into the field the angles made with such meridians by the line of railway at numerous

points of its course. By attending in the field to observations of these angles made with the needle of the instrument when out of sight of church-steeples and other objects which are known to be correctly fixed on the Ordnance Map, the leveller will be able, in any part of the country, to follow with ease and accuracy the precise line laid down on the map.

PRACTICAL REMARKS ON LEVELLING.

The Field Book.

The great requisites in keeping a field book for registering observations in levelling, are, clearness, distinctness, and a system of checking or verifying the accuracy of the calculations necessary for reducing the observed height of each point to its proper height above the datum line. The field book should therefore have lines ruled in ink to separate the *back* observations from the *fore;* it should also have two columns, one to enter the rises from one point to another, and one to enter the falls. A fifth column should be added for the reduced levels, or the heights above datum, and a sixth for the length or distance at which each observation is taken.

The following is recommended as an excellent

form of Level Book, as it combines all the requisites which should be attended to in levelling operations; and nothing short of excessive carelessness in working up the levels can lead to an error of calculation in such a book. I need not weary the reader's patience by a description of all the various forms of Level Book used by engineers at the present day. At the same time, I feel compelled in honesty to pronounce a very sweeping censure upon most of them, and to say that during the recent unprecedented bustle in railway business, in the preparation of sections for parliament, several forms of Level Books have come under my notice, which are highly objectionable, either in the arrangement of the columns, or in the mode of working them. With such Level Books as I have lately seen—in the hands too, of men not remarkable for the highest degree of care and coolness—I cease to wonder at errors of the greatest magnitude creeping into levelling operations at a stage when they ought to be distinguished by absolute accuracy; namely, in the mere mechanical reduction of the levels after they have been taken in the field, and are beyond all the numerous and sometimes unavoidable chances of error by which they are there attended.

FORM OF

Distance.	Back. ⊙	Fore. ⊙	Rise.	Fall.	Heights above Datum.
Miles. Links.					
16 = 3590	218.24	- -	218.24	- -	218.24 2.15
3760	5.80	3.65	2.15	- -	220.39 3.98
4220	6.18	2.20	3.98	- -	224.37 5.16
4630	8.35	3.19	5.16	- -	229.53 6.48
4950	8.53	2.05	6.48	- -	236.01 0.91
5130	2.05	2.96	- -	0.91	235.10 4.51
5510	8.40	3.89	4.51	- -	239.61 10.64
5840	15.00	4.36	10.64	- -	250.25 9.07
6200	14.35	5.28	9.07	- -	259.32 1.03
6730	11.16	10.13	1.03	- -	260.35 6.97
B. M.	9.21	2.24	6.97	- -	267.32 12.02
7300	0.18	12.20	- -	12.02	255.30 1.05
7580	5.20	6.25	- -	1.05	254.25 4.74
17 miles	2.65	7.39	- -	4.74	249.51 2.23
340	3.50	5.73	- -	2.23	247.28 3.38
630	1.12	4.50	- -	3.38	243.90
	327.08 83.18	83.18	268.23 24.33	24.33	
	243.90	- - Rise	243.90	- - Rise.	Carried on

This form of Field Book with the calculations used in working it are so simple, as scarcely to require explanation. The reading of the *back* staff is to be entered in the column headed "Back ⊙," and

FIELD BOOK.

LOCATIONS.
Brought forward
Centre of public road from Hampton to Welney.
B. M. The stump of a tree in the line on north side of this road at top of bank, 30 links from corner of fences, cross cut on top of stump where staff was held.
Carried on.

the reading of the fore staff in the column headed "Fore ⊙." Where the reading of the back staff is greatest, the ground is evidently rising, and the difference between the two readings is to be entered

in the column headed "Rise," and where the back staff is the least, the ground is evidently falling, and the difference is to be entered in the column headed "Fall." The column headed "Heights above Datum" contains the addition and subtraction of each successive rise and fall respectively, and always indicates the height above *datum* of the point on which the fore staff was held. The column headed "Distance" contains the length in chains and links from some fixed spot to the point at which the fore staff is held, so that opposite to the point indicated by each successive distance is the height above datum of that point.

INTERMEDIATE LEVELS.

It will be observed in this specimen of Level Books, that there is one entry in the fore column exactly the same as the following entry in the back column. In this case, as for instance, where the distance is 4950, the fore staff has been read off at this distance, in order to enter a variation of the surface, and has been taken on to distance 5130 without any removal of the instrument. This, it will be observed, saves a setting of the instrument, because the effect

of entering this *intermediate sight*, as it is called, at distance 4950, is exactly the same as if the fore staff had been read off at that distance, the instrument removed, and the staff at 4950 again read off as a back sight. It is evident that the insertion of these intermediate sights will greatly facilitate the labour of the leveller, particularly in taking a minute section intended for plotting to a large scale, and requiring every undulation of the surface to be shown. They are also extremely useful for entering the separate heights of the centre and sides of a road, of the sides, banks, and bed of a river, and for many other cases which the practical leveller will readily perceive.

I cannot too strongly reprobate the practice of entering these intermediate levels in a separate column, as taught by some professors and practised by some levellers. It leads, in my opinion, to unnecessary intricacy and confusion, and is altogether opposed to that clearness and simplicity which should distinguish a Level Book, without, at the same time, possessing one single recommendation that I could ever discover.

It is a feature peculiar to these intermediate sights

that they need not be taken with the same accuracy as the others, which may be termed station sights, and which are taken from two separate positions of the instrument. The reason of this is evident. The station-sights become part of the chain of levels, and an error made in one of them is carried on to the end of the levels, and consequently through the section. But an error in an intermediate sight affects only itself, and is not carried on even to the next observation.

An example will best illustrate this distinction. Suppose, at the distance 1650, a back sight of 10.30 has been observed; at the distance 2380, a fore sight of 14.65; and at 1830 an intermediate sight of four feet has been taken; these observations will then stand thus: —

Distance.	Back.	Fore.	Rise.	Fall.	Heights above Datum.
1650					306.20 6.30
1830	10.30	4.00	6.30		312.50 10.65
2380	4.00	14.65		10.65	301.85

From which it appears that the height at 1830, the place of the intermediate sight, is 312.50 above *datum*, and at 2380 the height is 301.85.

Now, suppose the intermediate sight to have been read five feet instead of four, then the observations will stand thus: —

Distance.	Back.	Fore.	Rise.	Fall.	Heights above Datum.
1650					306.20
					5.30
1830	10.30	5.00	5.30		311.50
					9.65
2380	5.00	14.65		9.65	301.85

Showing, that although the height at 1830, the place of the intermediate sight, is a foot less than before in consequence of the difference in the reading, the height at 2380 is 301.85, the same as before, and of course none of the future heights will be affected by the error assumed to have been made in the intermediate sight.

This distinction between the intermediate and fixed sights, when rightly understood by the beginner, will save him much trouble in taking finished levels for parliamentary and other purposes, in which great accuracy is required. He will perceive that the height of the instrument, when it happens to be in the line, may often be entered with advantage as an intermediate sight, as it is always possible to estimate the height of the centre of the tube within an inch or two,

which is less than can be plotted on the ordinary scales of sections. In passing over a hill or over any little ridge in the contour of a country, if the instrument be placed on the summit of it, and its height entered as an intermediate sight, it will commonly save one setting. Also, in passing across either a ridge or a valley, the staff may be roughly read off as an intermediate sight, and the staff-holder directed to proceed to the next place where an observation is required, without the labour of specially setting the instrument close to the bottom of the valley or top of the hill, as the case may be.

BENCH MARKS.

These are fixed points or stations on which the staff is held, and whose height above *datum* is consequently determined for the purpose of being referred to on any future occasion, either for the purpose of checking the accuracy of the levels or for the convenience of commencing a new series in some other direction. They may, therefore, be considered as permanent stations, whose exact height is determined, and which can at any time be found and identified as the exact points referred to in the field book. The objects commonly used for bench marks

are the hooks and tops of gates, the copings of drains and culverts, the sills or steps of doors, &c.; while some levellers prefer a stout stake driven into the ground. In passing across an enclosed and cultivated country, the leveller can never be at a loss for bench marks; and he may with safety use any of the objects just mentioned, as there is little danger of their being removed. It is most essential with respect to bench marks that the description should be so clear as to prevent any possibility of the mark being mistaken, either by the leveller himself or by any other person who may have occasion to find it from the description in the Level Book. The best rule is, to describe each bench mark as if you were talking of it to a stranger, not as if you only intended it for your own information, relying on your memory to supply the imperfection of the description. It is useful to mark in some way the object taken for a bench mark, and to describe it somewhat in this form: — B. M. The invert of lower hook of gate, south side of road leading from Hackworth to Taplow, about 150 links west of line; cross cut on post. With this description before him, a perfect stranger passing over the line in which the bench mark has been taken can scarcely fail to discover it.

Instead of cutting a cross on the post or on any other wooden object taken for a bench mark, an operation which the attendant labourers will often neglect unless closely watched, I would suggest to the leveller the use of an iron punch, which, being struck with a hammer, will cut a mark of this shape $^{a}\overline{\wedge}^{a}$, the short horizontal line *a a* being fixed before the punch is struck to the exact level of the height at which the base of the staff was held. The advantage of this would be that the exact bench mark would always be identified: there would be no uncertainty, for instance, as to whether the top of the pin or the invert of a gate hook had been taken; and the person in search of the bench mark would always know it to be one from the peculiar form of the mark; whereas, an ordinary cross, scratched as it often is with a knife, might be overlooked, or might be imitated by some idle rustic, intent either upon mischief or amusement.

Bench marks should, in ordinary cases, be taken at distances of about half a mile apart, and it is a good rule to take one at the crossing of every road.

It is not advisable to enter the height of a bench mark as an intermediate sight, because that very

bench mark may be used for checking the levels; and it is obvious that its height may be either right or wrong, without affecting the accuracy of the series, or without affecting a single other observation.

If the staff placed on a bench mark be read off on any occasion as an intermediate sight, it must be done with the greatest care, and not loosely observed, as in the case of ordinary intermediate sights.

THE STAVES.

There is nothing in levelling operations of greater importance than the employment of proper staves, because these are used, as already explained, at each setting of the level to measure the height from the surface of the ground to a point on a level with the telescope of the instrument. The graduations should, therefore, be very accurate and distinct, and the staff itself very straight and steady, otherwise it will be bent by the wind, and an incorrect reading will be the consequence. Until within the last few years a staff made by Messrs. Troughton and Simms, in two pieces, one sliding in a groove cut on the other, and furnished also with a sliding vane, which had to be set by hand, was almost universally used.

With staves of this kind the levels were taken for all the canals and all the principal drainages of this country—works in which the highest degree of accuracy is essential. The great defect of these staves, however, was, that the leveller could see nothing but the vane, and he had to trust to the staff-holder, after setting the vane, to keep it precisely in its place, otherwise an error would be made in the reading. Hence it was highly dangerous to use them without regularly trained and very careful staff-holders, who, it may be supposed, were not to be met with on every emergency. These defects in Troughton's sliding staff gave rise to the invention of *reading* staves, in which the feet are decimally divided on the face of the staff, and the figures painted in large bright characters, so as to be easily legible through the levelling telescope. With such a staff the leveller books his observation before removing his instrument; and he does so quite independently of the staff-holder, who has only to hold his staff steady and upright. Two kinds of reading staves are commonly sold by instrument-makers, one bearing the name of Sopwith, and the other said to be the contrivance of Mr. Gravatt. The former is constructed to close up on the principle of the

telescope, and the three pieces of which it is composed shut up into a length of about five feet. Mr. Gravatt's staff is also in three pieces, which, when joined together, form a staff about seventeen feet long, and they pack up side by side into a convenient length for carriage. One great objection to each of these staves is, that they are not steady, but are liable to be much thrown out of perpendicular when used in windy weather. They are also easily broken and put out of order; but the most serious defect is the want of a vane, which cannot be used with either of them; so that however desirable it may be on some occasions to take a long sight, it is quite impossible to avail one's self of the power of the telescope beyond the distance at which it will read the figures on the staff. This is highly objectionable in taking trial levels, or in levelling rapidly from point to point to ascertain simply their difference of level without requiring to show the details of the intermediate surface. It is scarcely possible to read with accuracy one of the common staves at a distance of six chains; whereas a vane-staff, such as I am about to describe, may be read with perfect ease at the distance of a quarter of a mile.

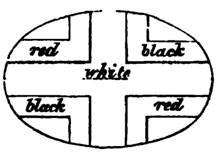
I contend that the staff for levelling purposes

should be in one piece, should be graduated into feet, tenths, and hundreds on one side, and be furnished with a vane sliding on the other side. Such a staff may be made in this way: — Order from the carpenter a piece of straight clean pine, free from knots and splinters, about fifteen feet in length, × two inches, × one inch; and observe particularly that the wood must not have been tapped, and must contain its natural sap and resin. Let this be painted all over with several coats of white paint. Then divide one side of it very accurately into feet, divide each foot again into ten equal parts, and subdivide each of these tenths into ten other parts, which will each be the hundredth of a foot. Let each foot and each tenth be denoted by a black stroke across the face of the staff, and each hundredth by a black stroke half way across it. Each of these strokes should be the hundredth of a foot in thickness, and then four half strokes between each tenth division will indicate the hundredths. The staff being thus divided, mark each foot by a red figure, and each alternate tenth by a black figure, making all the figures the tenth of a foot in length, so that each will exactly fill the space between two of the tenth divisions. The bottom of each figure will then be one of the odd tenths, and

the top one of the even tenths, the graduation being as follows:—2. 4. 6. 8.—one foot; 2. 4. 6. 8.—two feet, and so on.

The vane is the next consideration. This may be made very simply, of a plate of iron, with two cheeks riveted through it, and bent so as to clasp the staff and slide easily upon it. The face of this vane should be painted white, and then divided into compartments, which should be painted red and black, in oil colour, in order to make it more distinctly visible.

The annexed cut shows the face of the vane, in



which the horizontal white space in the middle is intended to be cut by the cross wire of the levelling telescope. Such is the face of the vane, at the back of which, exactly corresponding with the centre of the white space, there must be a notch or nick cut in the metal, in order to show by its contact with the divisions on the staff the exact height of the centre of the vane. Now as the staff to which this vane is applied is fifteen feet in length, all in one piece, it is evidently impossible for the staff-holder to set the vane by hand at all parts of the staff. It is therefore necessary to use a cord and

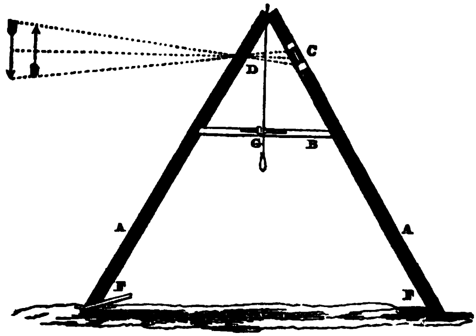
pullies, which are thus employed: — A small brass or wooden pulley, about two inches in diameter, is to be fixed in the wood at each end of the staff, and one cheek of the vane is to be provided with a ring, to which each extremity of the cord is to be attached. A piece of common window cord, red, green, or any other colour, is then to be fastened to the ring just mentioned, to be then passed through one of the pulleys, then along the staff through the other pulley, and back to the ring to which it was first fastened. By means of this cord the staff-holder can readily raise or depress the vane according to signals to be given by the leveller, who can thus cause the vane to be set with the greatest nicety to the exact level of the horizontal hair of the telescope.

When the vane is set, the staff-holder pressing the strings and staff tightly in his hands to prevent it from slipping, may lower the staff, and read off the height of the vane.

It has already been explained, that the principle of taking a continuous line of levels depends for its accuracy upon the regular determination of the height or depth of each successive point of the surface above the preceding. It will follow from this,

that the staff which during one observation is held on any particular spot as a fore station, must during the next observation be held on the same identical spot as a back station. If we suppose, during any back observation, that the staff is held an inch higher or lower than during the preceding fore observation, it is evident, that an error of exactly one inch will be made in the series of levels; and hence the greatest caution is required on the part of the staff-holder, whose duty it is to turn the staff round for the back observation, without allowing its base to be one particle higher or lower than when it was held for the fore observation. It is seldom that a back observation is made with the staff *higher* than at the fore observation; but in the hands of a careless staff-holder the *reverse* is often the case; namely, that the staff is held at a lower level being pressed into the ground, and thus made to yield a higher reading to the person observing with the instrument. In passing over the soft ground of newly ploughed or harrowed fields, an inch, or even two, may easily be lost every now and then in this way, and a serious error will thus be the consequence in the course of a day's levelling. To guard against this, it is usual to provide the staff-holder with some

flat, hard substance, as a piece of tile or slate, which, lying flat on the ground, cannot readily be pressed in, and this will serve also to mark the exact spot as to position in which the staff was held, and prevent the man from losing his place through inattention. There is a simple instrument called a tripod, sold for this purpose by the instrument makers, being simply a plate of iron with a small rounded projection in the centre, two small spikes at the side to fix it in its place, and a short chain to lift it by when the staff-holder wishes to remove from his place.



THE A LEVEL,

FOR THE USE OF WORKMEN

IN THE DRAINAGE OF LAND, THE FORMATION OF WATER MEADOWS, THE MAKING OF ROADS, AND ALL WORKS REQUIRING A REGULAR FALL.

INVENTED BY

MR. BAILEY DENTON, SURVEYOR.

THE Woodcut above shows the instrument — its figure will explain the reason of its being called the "A Level;" while the observer will comprehend at a glance its portability, and the facility with which it may be used either on the surface or in the trench. The bar B turning up on a hinge and falling into grooves cut in the legs A, these legs may be closed, as a pair of compasses fold; and the whole may be

used as a rod for measurement. The legs A are sufficiently narrow to stand in the narrowest trench; while the false feet F afford the means of stationing the instrument on the surface.

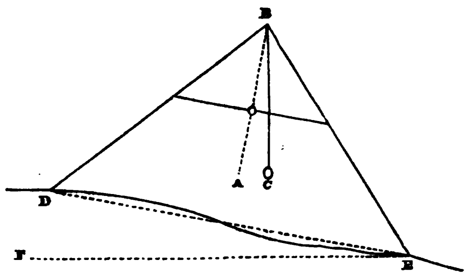
The object of the instrument is to assist foremen and workmen in testing and preserving a uniform fall in all works requiring such regularity. A spirit-level, if understood by workmen, is a thing easily put out of order, and is at all times liable to be broken; its use, therefore, is dreaded by workmen, as a process involving too much time, care, and precision, for their fingers to perform.

In draining and sewering, for instance, if the first object of the operator is to direct his drains according to the best fall of the ground; the next point of importance is that the floor of the trench, and the course of the tiles, soles, or bricks, should be even and regular from the top to the bottom of the drain. Any hollow in the drain intercepts the sedimentary matter which the flow of the drain-water would otherwise carry out with it; the sectional area of the water-way is thereby lessened, and the sediment, gradually accumulating, after a time causes a stoppage, the drain bursts, and the work has to be re-done.

The Level placed in the trench, as it is dug preparatory to laying in the tiles, indicates by the plumb-line any irregularity bad workmanship may occasion. Such use of the instrument is merely analogous to the mode by which the carpenter applies his square and plummet. It is my wish to prove that the extended principle upon which the A Level is based is so sound, that if accurately constructed, the instrument cannot work otherwise than with perfect efficiency, *in determining the average fall of surface between any two spots within sight of each other.*

It should be observed, that the legs of the instrument being equal in length, form, with the base upon which they are placed, an isosceles triangle, and that, when that base is perfectly level, the plumb-bob pendent from the apex must necessarily divide the triangle directly in half. This admitted, it is equally clear that by means of a bar connecting the two legs at any given distance, and exhibiting on its face the centre or half of the angle at the apex, any person is competent, guided by the plumb-line, to raise or depress one leg until it stands on a level with the other; the plumb-line will then hit the centre.

Now, as the plummet will always hang vertically, by reason of its weight, any rise or depression of either leg is immediately indicated on the connecting bar by the equivalent deviation of the plumb-line from the centre.



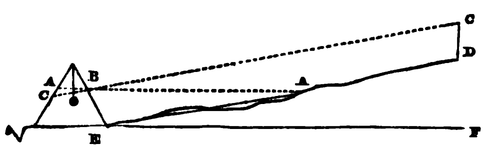
The angle A B C is equal to the angle D E F, *i. e.* the angle made by the hypothenuse or surface with the horizontal line, is equal to the angle of the line dividing the triangle in half, with the vertical line.

Thus, the difference of height between D and E may be calculated by multiplying the natural sine of the angle D E F, (read off on the bar as A B C, *if the index represents degrees,*) by the length of the ground spanned between E and D. In the A Level this is already done; and instead of degrees and minutes, inches and quarters are divided on the bar, so that the operator may at once read from it the

difference of height between the two spots upon which the instrument stands, and *vice versâ*. If it is required to sink one leg an inch below the other, the ground is lowered until the plumb-line strikes the one-inch division of the index on the bar.

It will be seen, that at a certain distance from the apex, on each leg, a line of sight is shown. On the one leg there is a sliding sight-hole answering to a fixed index, agreeing with that on the bar B; on the other leg there are cross hairs fixed, the centre of which is exactly the same distance from the apex as the nonius of the index on the opposite leg. The line of sight, therefore, from these two points is ever parallel with the base of the instrument.

To arrive at the average fall of surface from the top to the bottom of a field, the instrument must be placed on a level by means of the plumb-line. The operator must then send forward his assistant-workman to the spot D, at which he intends to end his



drain, with a stick marked by a paper fixed in it at a height C above the ground, agreeing with the

height of the cross hairs B, above the base of the instrument. He then slides up or down the sight-hole until he fixes the cross hairs upon the paper in the stick.

This line of sight, C B C, is parallel with the general line of surface, E D (regardless of its sinuosities), and therefore forms, with horizontal line of sight A B A, an angle C B A, equal to the angle D E F, formed by the datum horizontal and the surface.

Now, as the opposite angles of lines crossing each other are equal, the angle A B C is equal to the angle C B A; and we have shown that the angle C B A is equal to the angle D E F; therefore A B C is equal to D E F, and consequently you are enabled to read from the index at C the angle *converted into inches and quarters,* which is common to the whole distance from E to D. The height thus read off is transferred to the bar B, and retained by the shifting limb G (see the Woodcut), to the edge of which the plummet is afterwards worked. This limb is used only to save memory, and assist the man who cannot read.

When folded it forms a very portable five-feet staff. *Price* 30*s.*

DIRECTIONS FOR USE.

A stick, indicating clearly by paper or otherwise the height of the line of sight in the instrument, must be stationed at the point it is intended to bring out the drain or end the work. The instrument being set to a true level by means of the plumb-line, the operator looking through the eye-hole in the sliding vernier at C brings the cross hairs at D in a line with the mark in the distant stick.

He then reads from the index opposite the eye-hole the average fall to which he is to set the shifting limb at G in the bar B for the men to work to. The only direction necessary to be given to them is, that they are to bring the plumb-line to the edge of the shifting limb, as they would set a line to the centre of a carpenter's square.

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106	Twelve-foot Levelling Staff, common, portable, with or without level	*1l.* 10*s.* to	2	12	6
107	Ditto, for reading without an assistant		4	4	0
108	Land Chains	10*s.* to	1	1	0
109	Tape Measures, in brass or leather cases	5*s.* to	3	3	0

*** *In giving orders by Post it will only be required to state the Number placed to each Instrument.*

LIST

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